Máster Internacional en
GESTIÓN PESQUERA SOSTENIBLE
(7ª edición: 2017-2019)

TESIS

presentada y públicamente defendida
para la obtención del título de

MASTER OF SCIENCE

Spatiotemporal variation of fishery patterns, demographic indices and spatial distribution of European hake, *Merluccius merluccius*, in the GSA 01 and GSA03

HANANE EL YAAGOUBI
Septiembre 2019

MASTERENGESTIÓNPESQUERASOSTENIBLE
(7ªedición: 2017-2019)

Spatiotemporal variation of fishery patterns, demographic indices and spatial distribution of European hake, *Merluccius merluccius,* in the GSA 01 and GSA03

Hanane EL YAAGOUBI

TESIS PRESENTADA Y PUBLICAMENTE DEFENDIDA PARA LA OBTENCIÓN DEL TÍTULO DE *MASTER OF SCIENCE* EN GESTIÓN PESQUERA SOSTENIBLE

Alicante a…09.de Septiembre de2019

Spatiotemporal variation of fishery patterns, demographic indices and spatial distribution of European hake, *Merluccius merluccius*, in the GSA 01 and GSA03

Hanane EL YAAGOUBI

Trabajo realizado en *el Centro Oceanográfico de Baleares (COB) del Instituto Español de Oceanografía (IEO),* España, bajo la dirección del Dr.Manuel HIDALGO y la Dra. Pilar Hernández

Y presentado como requisito parcial para la obtención del Diploma *Master of Science* en Gestión Pesquera Sostenible otorgado por la Universidad de Alicante a través de Facultad de Ciencias y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza(IAMZ).

V B Tutor y Tutora | Autora

Fdo:Dr.Manuel Hidalgo y Dra. Pilar Hernández... | Fdo: Hanane El yaagoubi.................

Alicante ,a 25 de Septiembre 2019

Spatiotemporal variation of fishery patterns, demographic indices and spatial distribution of European hake, *Merluccius merluccius*, in the GSA 01 and GSA03

Hanane ELYAAGOUBI

Trabajo realizado en *el Centro Oceanográfico de Baleares (COB) del Instituto Español de Oceanografía (IEO),* España, bajo la dirección del Dr.Manuel HIDALGO y la Dra. Pilar Hernández

Y presentado como requisito parcial para la obtención del Diploma *Master of Science* en Gestión Pesquera Sostenible otorgado por la Universidad de Alicante a través de Facultad de Ciencias y el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza(IAMZ).

Esta Tesis fue defendida el día 2 de Septiembre de 2019 ante un Tribunal Formado por:

- Presidente: José Luis Sánchez Lizaso (UA)
- Secretario: Bernardo Basurco de Lara (CIHEAM)
- Vocal: Encarnación Benito Revuelta (SGCN-MAPA)

Acknowledgement

I would first like to express my special appreciation and thanks to my thesis advisor Dr. Jose Manuel Hidalgo for his guidance, instructions and precious advices. He steered me in the right direction whenever he thought I needed it. He has shown me, by his example, what a good scientist (and person) should be.

I would also like to thank Dra. Pilar Hernandez, my co-advisor, for giving me this opportunity and for being involved in the elaboration of this work from the beginning to end.

I am also grateful to Dr. Jose Luis Sanchez, Dr. Bernardo Basurco and Dr. Aitor Forcada for their help and availability during this Master.

A special thank to all of those with whom I have had the pleasure to work during my stay in COB.

I would like also to thank Moroccan scientists of INRH for their collaboration namely, Dr. Malouli Idrissi Mohamed, Dr. Aziz Lamtai , Ms. Benziane Meryem , Dr. Masski Hicham and Dr.Setiih Jamal.

Nobody has been more important to me in the pursuit of this work than the members of my family. I would like to thank my parents, whose love and guidance are with me in whatever I pursue. They are the ultimate role models. Most importantly, I wish to thank my loving and supportive husband for his encouragement and patience.

Abstract

European hake, *Merluccius merluccius*, is one of the most commercialized species in the Alboran Sea and elsewhere in the Mediterranean Sea. In the Alboran Sea, European hake stocks are regularly assessed as shared stocks. However, there are no scientific evidences for shared or separate any stock in this area yet. As in most stocks on earth, boundaries of stocks (and the geographical subareas in the case of the Mediterranean Sea) have been established by the General Fisheries Commission for the Mediterranean, GFCM, based on political and statistical considerations rather than biological factors. In this respect, the multidisciplinary project TRANSBORAN, was built with the overall aim of reviewing stock units boundaries of the Alboran Sea stocks of the most relevant species, including European hake.

In this study and in the framework of the aforementioned project, published information and available data on European hake in GSA 01 (Spain) and GSA 03 (Morocco) are compiled to analyze the spatiotemporal variation of fishery patterns, demographic indices and length distributions of this species applying several methodologies. First, generalized additive models and dynamic factor analysis were applied on monthly time series of Landings Per Unit Effort (LPUE) of 13 ports in the study area to describe the seasonal and inter-annual variability and underline common trends between the two GSAs. Second, length distribution of the species was compared between GSAs and years. Finally, spatial distribution metrics in longitude, latitude and depth were calculated for both GSAs to compare the spatial distribution of the species and then examine their temporal variability and the potential density-dependent influence.

The present study shows that there is a clear seasonal and inter-annual variability on hake LPUE mainly associated to two common trends. The first is associated only to northern ports of Alboran evidencing a south-north difference. The second is associated only to eastern ports of both Alboran shores. Spatial metrics showed marked density-dependent inter-annual fluctuations in hake distributions, which were asynchronically related between GSAs, suggesting potential but intermittent linkages between GSAs driven by early life stages connectivity. Significant differences are also observed in hake length distribution within and between GSA 01 and GSA 03.

The results of this study shed new light on spatial dynamics of European hake population at the Alboran Sea and may have implications to provide scientific basis to future definition of the hake population structure and the differentiation of stock units in the Alboran Sea.

Keywords: *Merluccius merluccius* , stock delineation, population structure, Alboran Sea , GSA 01, GSA 03, fishery patterns .

Resumen

La merluza europea, *Merluccius merluccius,* es una de las especies comerciales más importante en el Mar de Alborán y en todo el Mar Mediterráneo. En Alborán, los stocks de merluza europea se evalúan regularmente como stocks compartidos. Sin embargo, todavía no hay evidencias científicas para soportar la evaluación y/o la gestión compartida o separada de los stocks en Alborán. Como en la mayoría de las poblaciones de peces en las otras partes del mundo, la Comisión General de Pesca para el Mediterráneo, CGPM, ha establecido límites de los stocks pesqueros (y las Subáreas Geográficas en el caso del mar Mediterráneo), basándose en consideraciones políticas y estadísticas en lugar de factores biológicos. A este respecto, el proyecto multidisciplinar TRANSBORAN, se diseñó con el objetivo general de revisar los límites de las unidades de los stocks de las especies más relevantes en el Mar de Alborán, incluida la merluza Europea.

En este estudio y en el marco del dicho proyecto, se compiló la información los datos disponibles de la merluza en GSA 01 (España) y GSA 03 (Marruecos) para analizar la variación espacio-temporal de los patrones de pesca, los índices demográficos y la distribución de tallas de la especies aplicando distintas metodologías. Primero, se aplicaron modelos aditivos generalizados y análisis de factores dinámicos en series temporales mensuales de Desembarques Por Unidad de Esfuerzo (*Landings Per Unit Effort, LPUE*) de 13 puertos en el área de estudio para describir la variabilidad estacional e interanual, así como identificar las tendencias comunes entre las dos GSAs. En segundo lugar, se comparó la distribución de tallas de esta especie entre GSAs y años. Finalmente, se calcularon métricas de distribución espacial en longitud, latitud y profundidad para ambas GSA para comparar la distribución espacial de las especies y examinar su variabilidad temporal y la influencia de la densidad poblacional.

El presente estudio muestra que existe una variabilidad estacional e interanual en las *LPUE* de merluza asociada principalmente a dos tendencias comunes. La primera está asociada solo a los puertos del norte de Alborán, lo que evidencia una diferencia sur-norte. El segundo está asociada solo a los puertos orientales de ambas costas de Alborán. Las métricas espaciales mostraron fluctuaciones interanuales dependientes de la densidad así como una relación asincrónica en la distribución en ambas GSAs, lo que sugiere potenciales pero intermitentes vínculos entre GSAs asociados a la conectividad en las primeras etapas del ciclo vital de la especie. También se observan diferencias significativas en la distribución de longitud de merluza dentro de cada GSA y entre la GSA 01 y la GSA 03.

Los resultados de este estudio arrojan luz sobre la dinámica espacial de las poblaciones de merluza en el Mar de Alborán y contribuirán a dar una base científica a la definición futura de la estructura de la poblacional de la especie y la diferenciación de las unidades de stock en esta importante zona de transición entre Europa y África.

Palabras clave : *Merluccius merluccius*, delineación de stock, estructura poblacional, Mar de Alborán, GSA 01, GSA 03, patrones de pesca.

Table of contents

List of figures

List of tables

List of acronyms

ANOVA	Analysis of Variance
CG	Center of Gravity
DFA	Dynamic Factor Analysis
EAG	Eastern Anticyclonic Gyre
EEZ	Economic Exclusive Zone
EH	European Hake
FAO	Food and Agriculture Organization of the United Nations
GAM	Generalized Additive Models
GFCM	General Fisheries Commission for the Mediterranean
GSA	Geographical Sub-Area
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
LPUE	Landings Per Unit Effort
MARSS	Multivariate Autoregressive State-Space Modeling
MEDITS	International Bottom Trawl Survey In the Mediterranean
NOAA	National Oceanic and Atmospheric Administration
RFOM	Regional Fisheries Management Organization
SIMWG	Stock Identification Methods Working Group
SNP	Single-Nucleotide Polymorphism
TAC	Total Allowed Capture
UNCLOS	United Nations Convention on the Law of the Sea
UNEP/MAP	United Nation Environment Programme / Mediterranean Action Plan
WAG	Western Anticyclonic Gyre

1. Introduction

The worldwide relevance of fisheries and aquaculture sector has reached considerable importance in the last years as many millions of people find in it a source of income and livelihood. Indeed, it is contributing significantly to food security by supplying a considerable quantity of animal protein to around 7.7 billion of people (The world Bank 2019), creating direct and indirect employment opportunities for many of them. However, marine resources are subject of fluctuations due to their vulnerability to climatic, environmental and anthropic factors, with act in synergy with their natural variability. From all those, anthropogenic drivers and particularly fishing is the main factor affecting fisheries production and marine wild resources. Actually, the fraction of fish stocks that are within biologically sustainable levels has shown a decreasing trend, from 90 % in 1974 to 66.9 % in 2015 (FAO, 2018) (Figure 1).To continue obtaining benefit from marine resources in the growing population scenario, sustainability of wild fisheries is essential. To achieve it, the first step is to undertake continuous 'health checks' known as 'fisheries assessments', which regularly analyze the status of all fish resources belonging to defined stocks. However, the delimitation of stock has been and still is one of the main challenges in fisheries ecology. Therefore, the fisheries sustainability is primary based on a correct stocks definition and identification to develop trustful and unbiased fisheries assessments that inform efficient management.

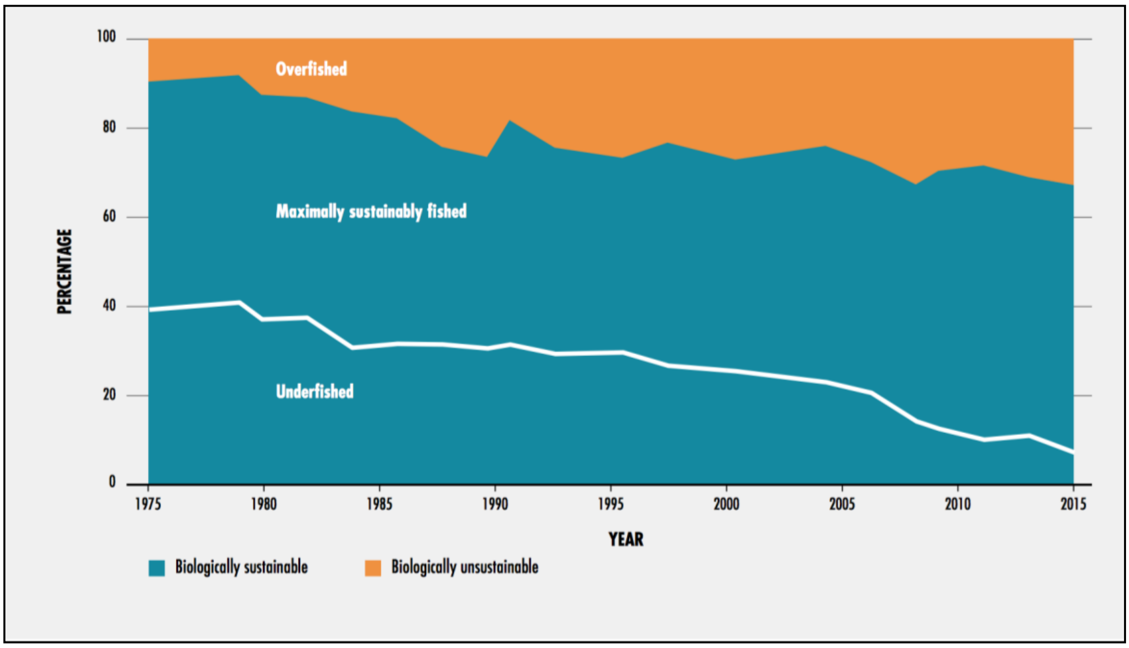

Figure 1. Global trends in the state of the world's marine fish stocks, 1974-2015(FAO, 2018).

1.1. Stock concept

Many definitions have been used throughout the fisheries literature to describe the stock concept. However, it is still difficult to give a clear definition to stock concept because of its highly dependence on the ecological and socio-political contexts, and the methodological approach used (Lleonart, 2015, Tanner et al., 2015). However, whatever definition one uses, the stock concept essentially describes characteristics of a population unit assumed homogeneous for particular management purposes (Begget al., 1999).

Nowadays, two main conventional definitions are used, FAO and NOAA definitions. The NOAA defined the stock as a "*group of fish of the same species living in same geographic area and mix enough to breed with each other when mature*". Looking at FAO (2003), this concept was introduced as a "*set of survivals of the cohorts of a fishery resource, at a certain instant or period of time, expressed in term of biomass or numbers*".

1.2. Stock identification

Since the United Nations Convention on the Law of the Sea (UNCLOS) was established, fisheries scientists, social scientists, policy makers and managers agreed on the paramount importance to define and distinguish between fish stocks that spend their entire lives in a country's EEZ from those that do not do it (Sumaila, 2019). In essence, to manage a fishery effectively, it is important to understand the stock structure of a specie and how fishing effort and mortality are distributed (Begget al., 1999).Indeed, an understanding of stock structure is dispensable to design appropriate management regulations in fisheries where multiple stocks might be differentially exploited (Begget al., 1999). To effectively doing that, it is also required to understand the spatial structure of species populations and to take into account its geographical boundaries. This understanding must be supported by mounting research on fish stock identification using a diversity of methods, which in some cases, have revealed inconsistencies between the spatial structure of biological populations and the definition of stock units used in assessment and management (Kerr et al., 2016).

From a fisheries management perspective, stocks, as mentioned in the above definitions are considered as discrete units with homogeneous vital rates that can be exploited independently of each other. However, the stock unit assumption is often violated leading to spatial mismatches that can trigger misleading results on stock assessment and obstruct sustainable fisheries management. Fori nstance, a stock that is assumed to be homogeneous may in fact be a mixed stock, composed of populations with special unique demographics and dynamics. Recommendations and strategies coming out from stock assessment for those stocks may be based on an erroneous perception of stock biomass and not account for differentiation in productivity among population components. In consequence, the harvest of a mixed stock, composed of unique populations of a single species, can potentially lead to overfishing the less productive populations and under-fishing in the more productive populations. Additional problems may occur in the assessment and management of units that are only a portion of a self-sustaining population, since catch advice will be estimated only for a portion of a subpopulation that may vary in its representation in a stock area over time. Furthermore, recent reviews on stock identification units conducted by Cadrin et al., 2019 to explore the impact of spatial population structure hypotheses one stimates of recruitment and population productivity on several species at different geographic areas such as New England yellowtail flounder, black sea bass north of cape Hatterras, or Atlantic and Pacific bleuefin tuna to name a few, has demonstrated that the spatial structure assumed in a stock assessment model is impacting the estimation of recruitment. Therefore, accounting for the most plausible stock structure can improve the accuracy of recruitment estimates.

Historically, several single techniques have been used for stock identification such as (Ihssen et al., 1981; Kumpf et al., 1987; Begg et al., 1999): population parameters, tagging, physiological and behavioral characters, morphometric and meristic characters, calcareous characters, genetics, and biochemical characters. Each technique requires very different methodology and, therefore, each data type must be treated separately. Also, each data type applies differentially to specific aspects of the stock definition. In 1992, the International Council for the Exploration of the Sea (ICES) established a "*Study Group on Stock Identification Protocols for Finfish and Shellfish Stocks*" to review methodologies of stock identification and develop a protocol for the application of stock identification results. Each year the established working group summarizes advances in the field of stock identification and provides recommendations on specific stock identification issues related to ICES advice. New technologies advances, developments in molecular biology, electronic tags, chemical methods, and image analysis have served to improve many stock identification approaches (Cadrin et al., 2015).

According to the latest report of the *Stock Identification Methods Working Group* (SIMWG) published on 2018, ten techniques have been mainly used in the last years to ICES stock identification: a) genetics, b) growth marks in calcified structures, c) life history parameters, d) morphometrics/ meristics, e) tagging, f) otolith shape, g) otolith microchemistry, h) parasites, i) simulation approaches and j) interdisciplinary approaches.

Nowadays, there is a growing interest for integrating the results of many different methods in a multidisciplinary platform. The 'holistic' stock identification maximize the likelihood of correctly defining stocks and appears to be pertinent for those fish species with complex stock identities or demographic structures. Furthermore, holistic approach helps to improve stock identification information provided by each technique by taking in account their spatial and temporal resolution. That is different methods are valid to show differences at different spatial (from local to regional) and temporal scales (from daily to evolutionary scales).In a single or a holistic approach, stock matching of biological processes and management actions is expected to include a variety of conflicting factors in the management strategy, such as biological, economic, social or even political factors. For long time, applying all those methods has not always been possible due to their inconclusive results or high costs of some of these techniques (Quetglas et al.,2012), especially for developing countries. Therefore, fishery scientists had to adopt compromises to delineate entities for monitoring harvested stocks, such as management units or geographic areas (Quetglas et al., 2012), which has undermined the credibility and certainty of stocks estimates and the efficiency of the applied management actions.

Stock identification does not only face biological boundaries, but it also challenges jurisdictional boundaries. Indeed, according to whether the stock unit is belonging to one, two or more states, a distinction is made between single stocks and shared stocks (i.e. transboundary stocks). Such distinction is crucial for developing management regimes that are likely to succeed. For fish stocks that are not shared, management responsibility is assigned and depends solely of local/regional institutions and policies. In contrast, when it is about a shared stock, fisheries assessment, management and monitoring are determined by all the countries that share the fish stock.

According to FAO, shared fish stocks includes the following:

- ✓ Fish resources crossing the EEZ boundary of one coastal state into the EEZ(s) of one or more coastal states - transboundary stocks;
- ✓ Highly migratory species, consisting, primarily, of the major tuna species
- ✓ All other fish stocks (with the exception of anadromous/catadromous stocks) that are to be found, both within the coastal State EEZ and the adjacent high seas - straddling stocks (e.g. some mesopelagic fish).

Shared stocks generally, and transboundary stocks particularly, are undergoing geographical shifts due to climatic change, reaching thus new territories and drawing new boundaries that may generate new potential conflicts over newly shared stocks. Pinsky et al., (2018) compared 1950–2014 with 2090–2100, and found that many of the world's EEZs are likely to receive one to five new, climate-driven transboundary stocks by the end of the century (Figure 2). Additionally, transboundary related conflicts might emerge in areas with restricted EEZ where stock boundaries remain unclear, which are indeed most of the cases.

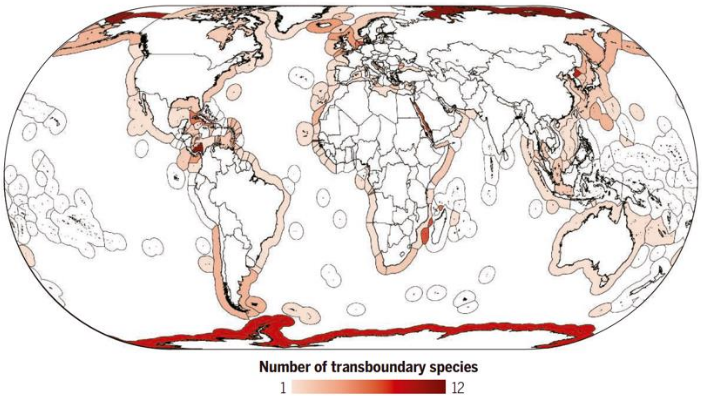

Figure 2. Projection of the number of transboundary stocks in the world by the end of 2100 (Pinsky et al.,2018).

1.3. Stock identification in the Mediterranean

In the Mediterranean, stock assessment and fisheries management are highly dependent on the division in Geographical Sub-Areas (GSA) of the GFCM. The definition of GFCM-GSA was done based on political and statistical considerations rather than biological or economic factors. In total, thirty GSA (Figure 3) have been delimited in the ad hoc Working Group on Management Units Definition and Limits held in Alicante (Spain) from 23 to 25 January 2000. The name GSA was assigned to these management areas at the 26thsession of the GFCM.

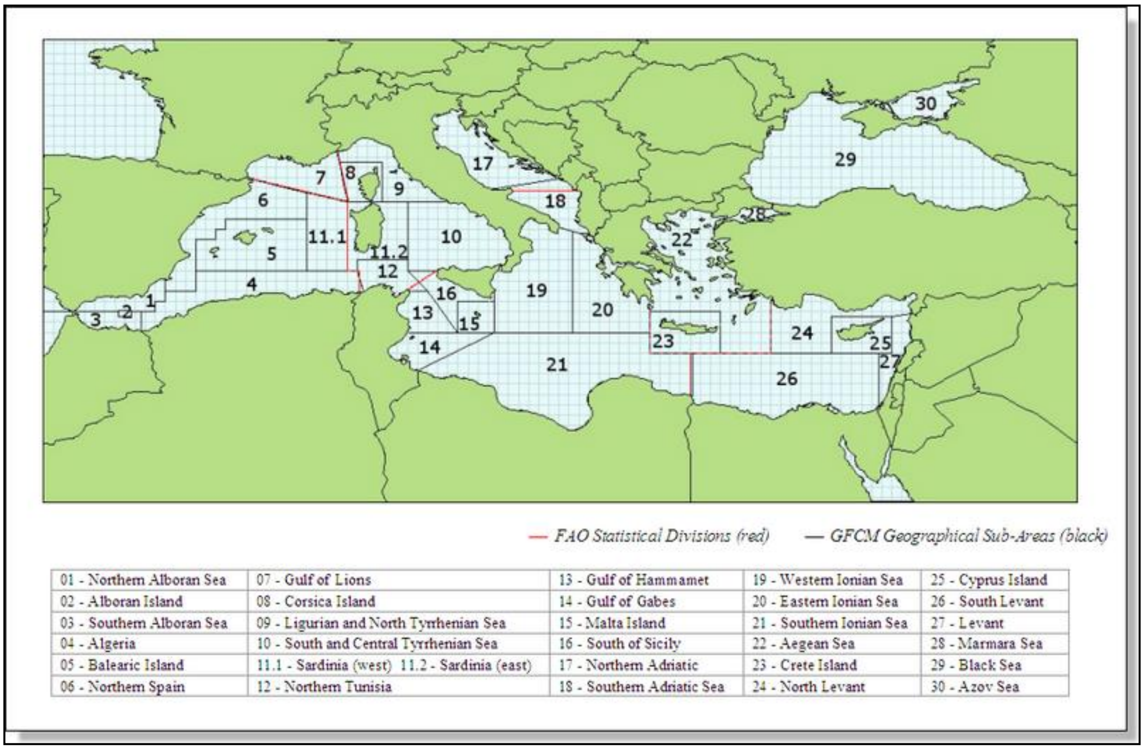

Figure 3. Subdivision of Mediterranean and Black Sea GSAs by CFGM.

The importance of an adequate stock identification and the increasing evidences of inconsistencies between the spatial structure of biological populations and the definition of stock units have led to several projects to address the stocks identification. This is the case of the STOCKMED project, funded by the EU over the whole north (only European countries) Mediterranean Sea, and more recently the TRANSBORAN project in the framework of the FAO cooperation project CopeMedII in the Alboran Sea (see below).

The Alboran Sea covers the areas from GSA 1 to GSA 4west and involves Spain, Morocco and Algeria, which makes Alboran one of the most paradigmatic examples of transboundary stocks in the Mediterranean Sea. The importance of delimitation of stocks in the Alboran Sea was already highlighted by the 39th Session of GFCM and the 18th session of its Scientific and Advisory Committee (GFCM, 2015) To solve this question for the most relevant and highly commercial species in Alboran Sea (sardine, *Sardina pilchardus*, hake, *Merluccius merluccius*, and blackspot seabream, *Pagellus bogaraveo*), TRANSBORAN research project is being developed under the framework of the FAO Regional Project “CopeMed-Phase II” and in collaboration with GFCM. CopeMed is a Project of Coordination to Support Fisheries Management in the Western and Central Mediterranean. It is executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Government of Spain and the European Commission (EC) (http://www.faocopemed.org/).

The project was built in 1996 at Venecia conference as a result of an initiative of Spain to consolidate the regional fisheries cooperation in the Mediterranean. The second phase was initiated in 2008 at the request of the participating countries which are Algeria, France, Italy, Libya, Malta, Morocco, Tunisia and Spain.

CopeMedII has three main objectives. The first is to strengthen national sub-regional and regional capacity (administration, stakeholders, and research institutions) in the identification of fisheries management strategies in accordance with the ecosystem approach to fisheries and aquaculture. The second is to improve capacity for fisheries monitoring, research and the preparation of scientific advice for fisheries management. And the third is to enhance regional cooperation and coordination for shared fisheries management, research, and capacity development (CopeMed II, 2018).

TRANSBORAN is among the activities of the second objective of CopeMed II for the period 2018-2020. It aims at investigating the spatial population structure and the identification the most likely stock units of sardine, European hake and black spot sea bream in the Alboran Sea according to a multidisciplinary approach (CopeMedII, 2017) .On the practical level, the project will reveal whether the current GSA boundaries are the appropriate spatial scale of assessment and management for the three objective species. The methodology of the project is based on a multidisciplinary approach of 6 steps suggested by Cadrin et al. (2014):

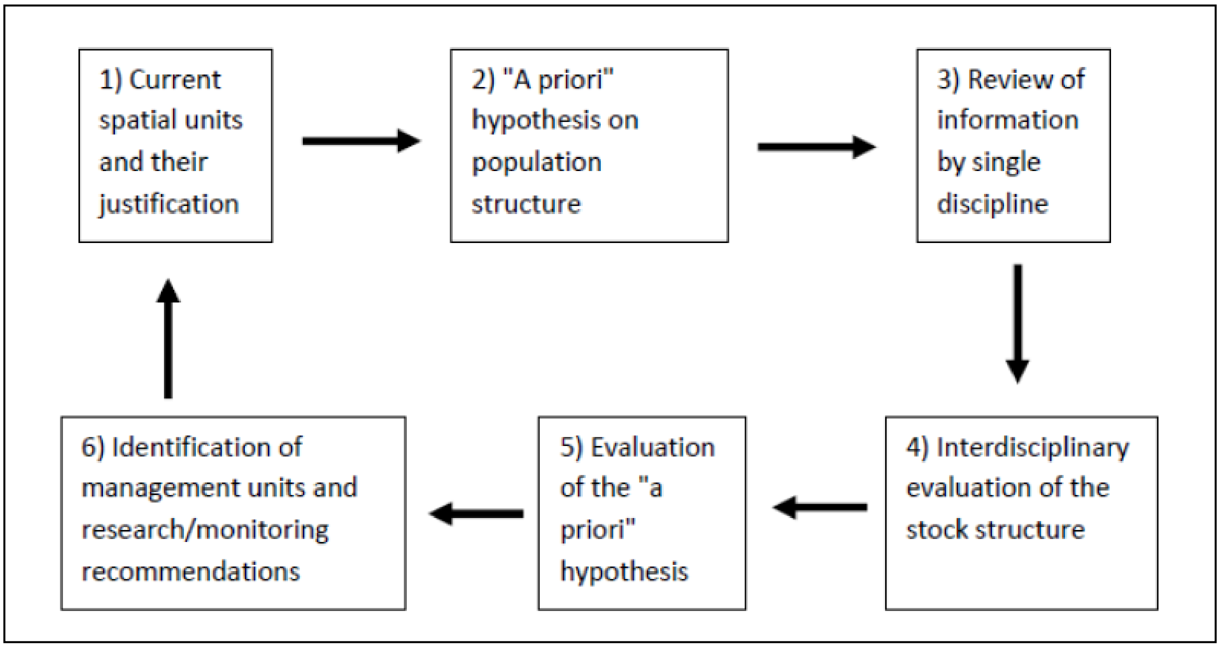

Figure 4. The logical framework in stock identification followed by SIMWG (Stock Identification Methods Working Group) of ICES (re-adapted from CopeMed II, 2017).

Following this logical framework in stock identification, existing data and information coming from different disciplines was used to test the hypothesis of the current stock delimitation in the Alboran Sea. An exhaustive sampling was designed to collect new data about the three targeted species with the purpose to cover the spatial and temporal scales of the life cycle of these species. 17 sampling sites have been selected for hake and sardine and 9 sampling sites for blackspot seabream where samples are available (Figure 5).The samples will provide biological material for each of the used disciplines as required. (CopeMed II, 2017)

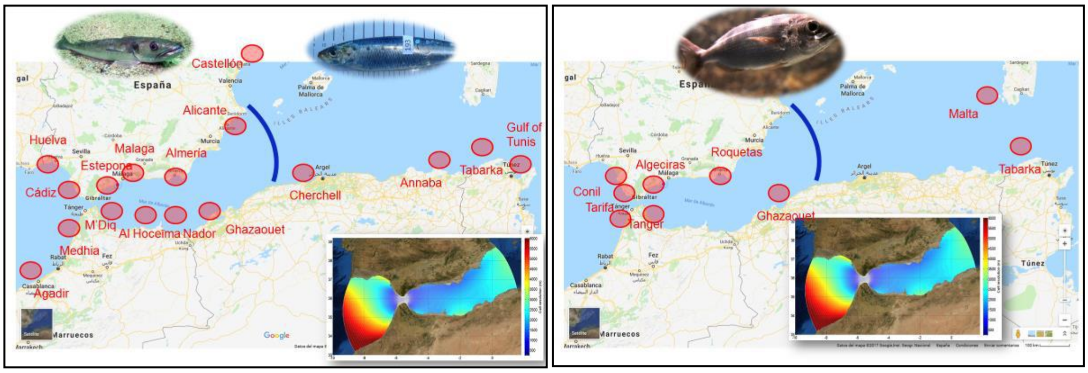

Figure 5. Sampling sites for hake, sardine and blackspot seabream.

The involved disciplines are (CopeMed, 2017):

- ✓ Hydrodynamic connectivity. It will consist on a description of hydrodynamic features that characterize the connectivity between spawning and nursery areas in Alboran and its source and sink outer areas. To achieve that, a hydrodynamical-biological coupled model will be developed by the Physical Oceanography group of the University of Málaga. This model can simulate the drifting of fish larvae in both space and time through Lagrangian drifter experiments.
- ✓ Genetic markers: Microsatellite and Single Nucleotide Polymorphisms (SNP) genotyping will be developed of both non-mature specimens collected from all sites in the Alboran Sea defined above, including neighboring Atlantic Ocean (Spain and Morocco) and neighboring Mediterranean Sea up to the Northern Spanish coast and towards Tunisia.
- ✓ Parasites as markers: Parasites of a known life cycle and geographical description and with a residence time on the fish host long enough such as *Anisakis* will be used as biological tag for stock identification.
- ✓ Otolith shape and elemental composition: Otolith shape using landmarks and microchemistry analyses at both otolith core and edge will serve as techniques for discrimination of populations.
- ✓ Body morphometry and meristics: analysis from pictures will be used as tools for body morphometry measurements. Meristic characters such as the number of vertebrae and branchispines will be used to study fish population variability in the Alboran Sea.
- ✓ Analyses of fishery patterns, demographics indices and life history traits. This method reposes in compiling and analyzing existing data and published Information on the biology and fisheries of the two species in the area, combining information from north and south Alboran Sea.
- ✓ Population dynamics simulation: It consists on evaluating the consequences of the different assumptions about stock boundaries based on the results of all the previous techniques to the stock assessment and the outcomes of management strategies.

1.4. Justification and objectives

Under the framework of TRANSBORAN project, the current TFM (‘*Tesis de Fin de Máster*’) project focuses on the sixth technique aforementioned, in which existing data and published information on the biology and fishery were compiled and analyzed for one of the species objective, the European Hake (*M. merluccius*).Besides its high commercial importance in the Alboran, European hake has shown a worrying situation as it suffers a generalized overexploitation state in the entire Mediterranean Sea. Of particular interest in the Alboran Sea, hake is assumed to be a shared stock and is consequently assessed commonly in the working groups since 2015. However, there is not any strong evidence of separate or shared stock units in this area.

The main objective of this study is to analyze the spatio-temporal variation of fishery patterns, demographic indices and length distribution of European hake, *Merluccius merluccius*, in the Mediterranean Spanish and Moroccan waters, with the aim of providing scientific support to the stock structure to be in place for this species in the Alboran Sea. To advance towards the overall objective three specific objectives are defined as follows:

1. **Analyze potential synchronic variation as well as to describe the main common modes of seasonal and inter-annual variation on LPUE series**: Monthly time series of landings and LPUEs of European hake have been collected for different ports to analyze potential synchronic variation as well as to describe the main common modes of seasonal and inter-annual variation.
2. **Analyze monthly size frequencies of landings per port to reveal potential spatial segregation in the mean size and in the seasonal evolution of the demography in GSA 01**: Monthly size frequencies of landings per port have been analyzed to reveal potential spatial segregation in the mean size and in the seasonal evolution of the demography in Spain and inter-annual evolution in Spain and Morocco.
3. **Calculate indices of abundance as well as temporal variation of spatial distribution of hake**: Abundance and biomass information obtained from scientific trawl surveys were used to calculate indices of abundance as well as temporal variation of centers of gravity of hake distributions.

2. Materials and methods

2.1. Study area

***2.1.**1. Geography and geomorphology*

The Alboran Sea is the westernmost part of the Mediterranean Sea. It can be considered as an elongated semi-enclosed channel that is connecting the strategic strait of Gibraltar to the open Mediterranean Sea becoming a transitional area with the Atlantic Ocean (Georgio et al., 1987). The Alboran extends from the Strait of Gibraltar to an adopted line running from Cabo de Gata (Almeria, Spain) to the Cape of Oran (Algeria) being, thus, an area shared between Spain, Morocco and Algeria (UNEP-MAP-RAC/SPA. 2014) (Figure 6). Its width is a minimum of 14 km in the Strait of Gibraltar and extends on up to about 180 km to the east with an east-west distance of approximately of 350 km (UNEP, 2015).

Figure 6.Alboran Sea map (WorldAtlas.com).

The Alboran is divided into two sub-units separated by the Alboran ridge (Mol et al., 2012): the Western Alboran Basin and the Eastern Alboran Basin. The Western Alboran Basin is located between the Strait of Gibraltar and the volcanic Alboran Ridge. It is 40 km x 22 km, connected to the Alboran Strait, and reaches a maximum depth of 1500 m (Mol et al., 2012, Parilla et al., 1987). The Eastern Alboran basin extends eastwards from the Alboran Ridge. It is smaller and deeper reaching a depth of 1800 m (UNEP, 2015). The Eastern Alboran is connected to the Algerian Basin to the east.

The topography of the Alboran Basin seafloor is characterized by pinnacles, knolls, banks, ridges and troughs. The width of the continental shelf varies from 2 to 10 km off the Spanish Coast and averages 5 km. Along the African Coast the shelf fluctuates from 3 to 18 km. The depth of the shelf slope varies from 100 to 150 m (Parilla and Kinder, 1987).

2.1.2. Circulation

The Strait of Gibraltar represents the only connection between the Mediterranean Sea and the Atlantic Ocean. The exchange through the Strait is usually described as a two-layer circulation, with a superficial Atlantic layer flowing towards the Mediterranean and an outflow of deep and high-density Mediterranean waters. The Atlantic jet that enters the Alboran Sea is the fundamental driver by the hydrodynamism within the Alboran (Perkins et al., 1990). This inflow feeds two anticyclonic gyres, which occupy almost the entire Alboran Sea (Figure 7). The Western Anticyclonic Gyre (WAG) is located roughly in the Western basin of Alboran with an apparent year around persistence. A less intense and recurrent anticyclone known as the Eastern Anticyclonic Gyre (EAG) occurs in the eastern basin. These two gyres prevail in the summer circulation regime and, the single anticyclonic gyre (WAG) and/or coastal jet regime in winter months (Vargas-Yáñez et al., 2002). Other studies evidenced the existence of a third central gyre that is displaced closer to the Western Anticyclonic Gyre during winter (Renault et al., 2012).

The Atlantic water jet produces an intensive geostrophic front in the north-western sector of the basin (geostrophic front of Almeria, Spain - Oran, Algeria), which coupled with westerly winds, causes intermittent upwelling events of deep Mediterranean water enriched in inorganic nutrients off the Málaga coast (Macías et al., 2011, UNEP,2015).

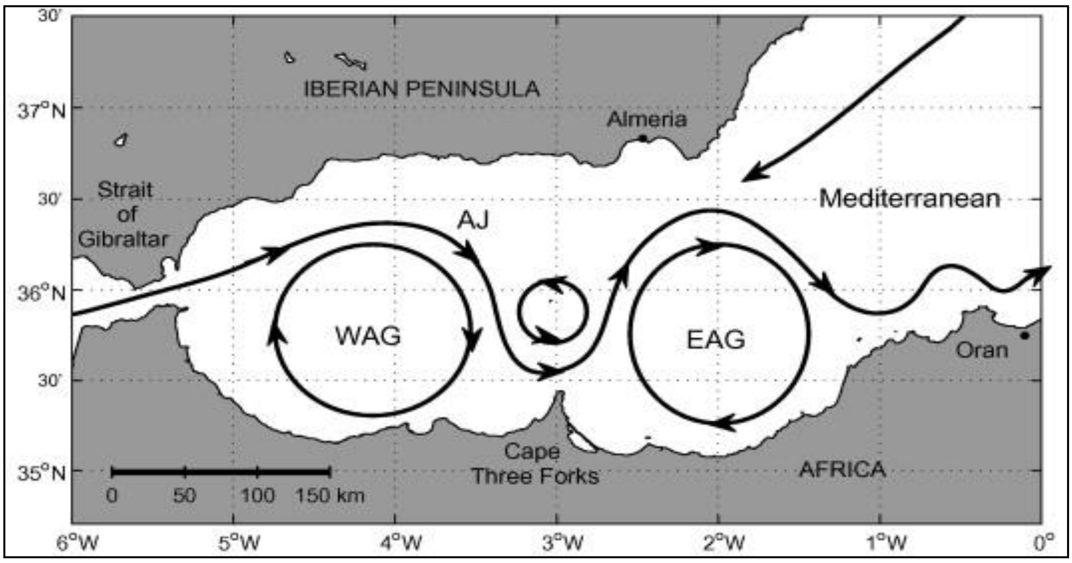

Figure 7. Alboran Sea circulation (from Renault et al., 2012).

2.1.3 Productivity

The Mediterranean Sea is generally known as an oligotrophic system (Garcia-Gorriz and Carr, 2001). However, there are some specific areas where the productivity is enhanced by the oceanographic activity. This is the case of Alboran Sea, where the presence of upwelling waters in the north western coast rich in nutrients and that fostered by a combination of several hydrological conditions generates higher planktonic productivity compared to other Mediterranean regions. In addition, geostrophic fronts occurring in the Alboran Sea are important due to the availability of nutrients for phytoplankton and the implication for the whole food web. Other important productive zones are the submarine canyons of the Alboran Sea for demersal fish (UNEP, 2015).

An important feature of Alboran productivity is its seasonality. Actually, the plankton maximum productivity occurs during spring, and autumn, and coinciding with spawning season of some species (Yebra et al., 2018). All this makes that in the north of the Alboran Sea there are important areas for the spawning of many of fish species near to the coast.

2.1.4. Fisheries

The Mediterranean fisheries are characterized by fragmented fleets, mainly composed by small artisanal vessels, use of a large number of landing sites and multispecies catches with low CPUEs (Hidalgo, 2007). Artisanal or small-scale fisheries (SSF) in the Mediterranean play also a significant social and economic role representing up to 84% of the fishing fleet. Total capture of Mediterranean fisheries production was 82700 tones averaged between 2014-2016 amounts (SOMFI, 2018). The western Mediterranean dominated the capture with 22 % of the total in landings in the Mediterranean. Small pelagic are the dominant species captured in the Western Mediterranean with 49% of total catch followed by large pelagic species. Demersal species are the last group that contributes in catches, despite being a complex group with more than 100 species with high economic value. In the Alboran Sea, the principal target species in order of importance are: bluefin tuna, sardine, European anchovy, European hake and red mullet (UNEP, 2014), with the fleet and ladings sites having the same characteristics as in other Mediterranean areas.

According to FAO (2018) more than 60% of Mediterranean and Black Sea assessed stocks, which represent only 28% of total landings (Lleonart et al., 2015), are fished at biologically unsustainable levels (SOMFI, 2018). The demersal stocks show the most worrying situation with the European hake displaying fishing mortality rates up to ten times higher than the optimal target (Hidalgo et al., 2018).

To keep fishing and taking benefits from the sea, an appropriate fisheries management is required. In the Mediterranean Sea it is complex due to the variety of landed species, small scale fisheries and heterogeneity in the governance between north and south countries. Nowadays, fisheries are controlled by fishing effort restriction, catch limiting and technical measures such as gear regulation, establishment of a minimum conservation reference size and areas and season closures. A relevant example is the recent adoption of an EU management plan for demersal stocks in the Western Mediterranean that, among other important elements, limit fishing to a maximum of 15 hours per fishing day and approved a ban on trawling within six nautical miles from the coast, except in areas deeper than the 100 m depth during three months each year. Each member state will determine those three months of annual closure, according to the best available scientific advice to ensure at least a 20% reduction of catches of juvenile hake (European Parliament, 2019)

In contrast to the Atlantic, no quotas or TACS are implemented for the Mediterranean stocks except for the Blue fin tuna (*Thunnus thynnus*) and for Swordfish fishery (*Xiphias gladius*). These management measures have been adopted following Regional fisheries management organizations (RFMOs) (GFCM and ICCAT) recommendations and obligations. The General Fisheries Commission for the Mediterranean (GFCM) is focused in the managing of the principal stocks in the Mediterranean and Black sea (demersal, small pelagic fish and invertebrates), while Commission for the Conservation of Atlantic Tunas ICCAT is focused only on managing highly migratory species.

In addition to the measures mentioned above, GFCM has recently adopted a ‘Mid-term strategy (2017–2020) towards the sustainability of Mediterranean and Black Sea fisheries (Mid-term strategy). The implementation of the strategy is expected to ensure that by 2020 the alarming trend in the status of commercially exploited stocks is reversed (FAO, 2016). This strategy involves Mediterranean and black sea countries, partner organizations having entered into a MoU (memorandum of understanding) with GFCM and all other relevant actors with interest on various aspects related to fisheries.

2.2. Studied species

2.2.1. Taxonomy

Hakes is one of the most highly worldwide exploited genus. At present, 13 species are known. Twelve have been described by Inad in 1981 and one was added by Lloris and Matallanas in 2003 all here below listed in a chronological order of first citation:

- *Merluccius merluccius* (Linnaeus, 1758);
- *Merluccius bilinearis* (Mitchill, 1814);
- *Merluccius albidus* (Mitchill, 1818);
- *Merluccius gayi* (Guichenot, 1848);
- *Merluccius capensis* (Castelnau, 1861);
- *Merluccius australis* (Hutton, 1872);
- *Merluccius angustimanus* (Garman, 1899);
- *Merluccius poli* (Cadenat, 1950);
- *Merluccius senegalensis* (Cadenat, 1950).
- *Merluccius productus* (Ayres, 1955)
- *Merluccius hubbsi* (Marini, 1933) ;
- *Merluccius paradoxus* (Franca, 1960) ;
- *Merluccius patagonicus* (LlorisetMatallanas, 2003);

The genus hake is distributed mainly in the Atlantic Ocean and the east coast of Pacific Ocean (Figure 8). The European hake, *Merluccius merluccius*, despite being one of the most studied species of the genus *Merluccius* is far from being the most important in terms of catches (Alheit and Pitcher, 1995).

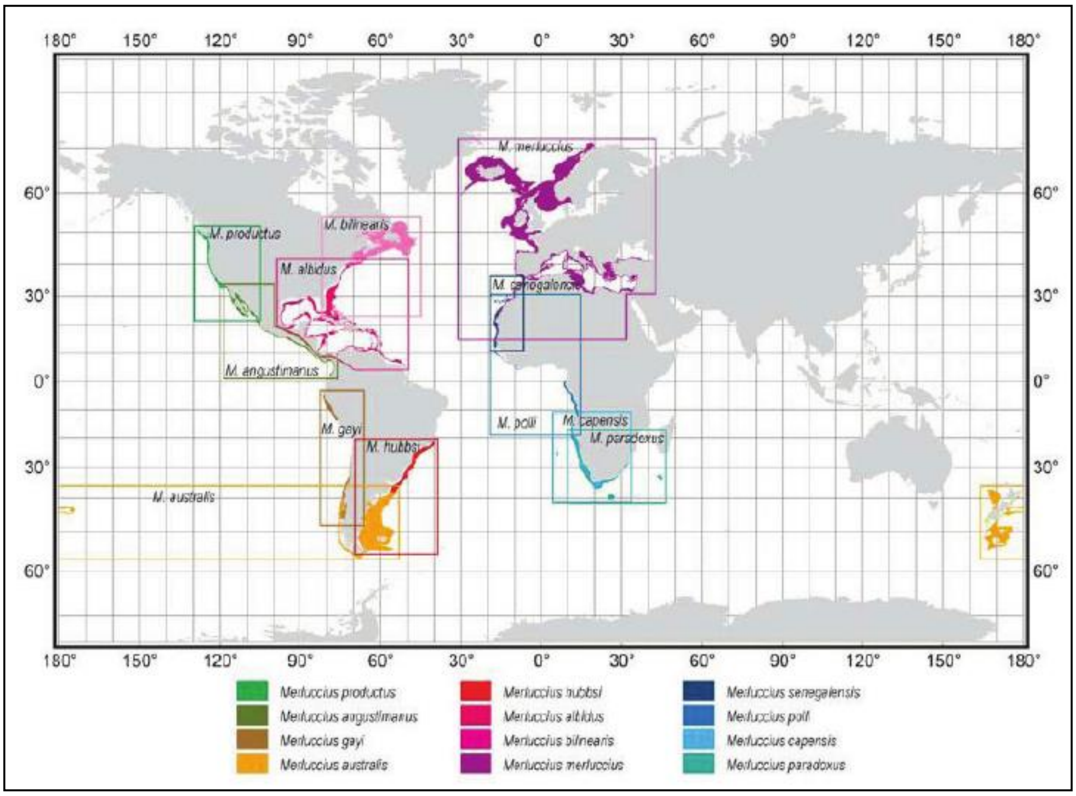

Figure8. Worldwide Geographic distribution of the genius Merleccius (FAO,2005).

It is known within the scientific community that the identification of hake individuals at species level is laborious. This difficulty is due to the morphological features that can show high similarities for some species of the genus. However, nowadays, new approaches such as DNA based identification methods are used and had shown much success (Quinteiro, 2001). The European hake taxonomy is summarized in the table 1:

Table 1. European hake taxonomy

Subphylum:	Vertebrata
Superclass	Gnasthosmata
Class	Actinopterigii
Division	Teleostei
Subdivision	Euteleostei
Superorder	Paracanthopterigii
Order	Gadiformes
Family	Merluccidae
Genus	*Merluccius*

2.2.2. Morphological features

European hake is characterized by a long body and rather slender compared with other hake species (Figure 9). Head length is between 25.1 to 30.5% of standard length. Measurements in relation to head length: upper jaw 47.8 to 53.5%; snout 30.2 to 34.5%; interorbital space 21.5 to 28.4%; gill rakers short and thick, with blunt tips; total number of gill rakers on first arch 8 to 11 (mostly 9 to 11). 1D 8 (10) 11 rays; 2D 35 (38-39) 40 rays; A 36 (38) 40 rays. Pectoral fins with 10 (14) 15 rays, length 14.1 to 18.7% of standard length, tips of pectoral fins reaching to level of anal-fin origin in small fish (less than 20 cm standard length). Ventral fins 14.0 to 19.1% standard length. Posterior caudal-fin margin usually truncate, becoming progressively concave with growth. Scales small, 127 to 156 along lateral line. Number of vertebrae 23 to 25 (precaudal) + 25 to 29 (caudal) 49 to 54 (total) (FAO 2005). The color is steel grey on back, lighter on sides and silvery white on belly.

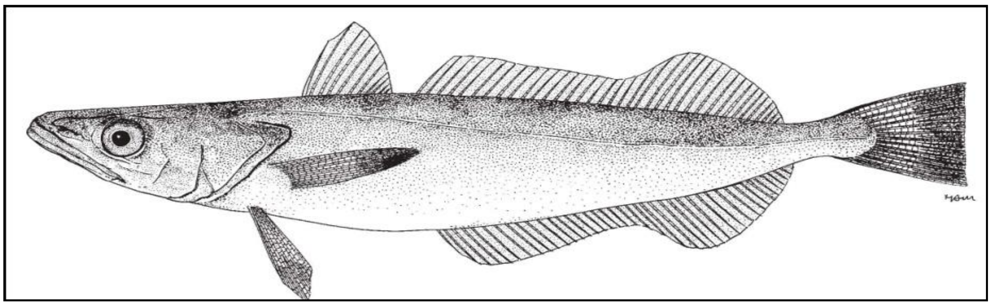

Figure 9. Morphology of the European hake (FAO, 2005).

2.2.3. Distribution

2.2.3.1. Geographic distribution

European hake is geographically distributed throughout the North-east Atlantic from north Norway in the North (around 70˚N) to the Guinea Gulf in the South (around 40˚S) (Figure 10). As regard the longitudinal distribution, European hake can inhabit as far as west Iceland and as far east as the Black Sea (40˚E). It is also found in the whole Mediterranean Sea. Even though it has a more extended range of latitudinal and longitudinal distribution, compared to other species, European hake is a tempered waters specie but with the high adaptive capacity and phenotypic plasticity (Hidalgo, 2007).

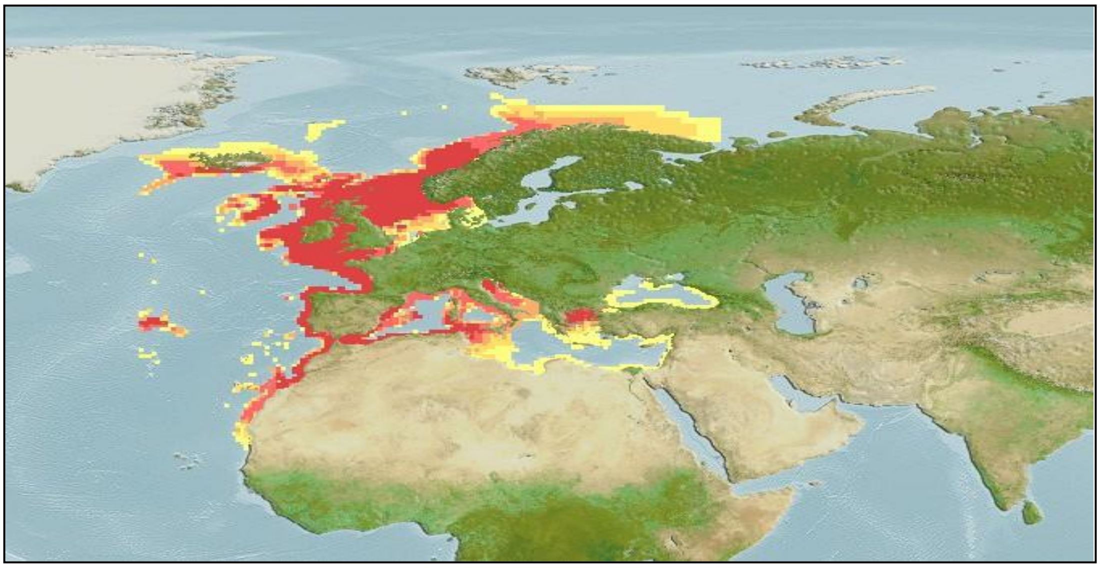

Figure 10. European Hake geographical distribution (Fishbase).

In the Alboran Sea, the geographical distribution of hake is heterogeneous in GSA03 with areas of higher concentration in the east. The largest concentration area is located off Kariat Arkman (Nador). Other areas of intermediate concentration are located in the center, on either side of the Al Hoceima region (INRH, 2018) (Figure 11). Likewise, in GSA 01, the distribution is also heterogeneous but longitudinally similar to Morroco with higher abundances towards east in the Almería Bay (.

2.2.3.2. Bathymetric distribution

The bathymetric distribution of hake in the Mediterranean displays a wide range stretching from 25 to 1000 m depth. However, the higher densities are observed at depths ranging from 100 m to 400 m where the most nursery areas are located in the Mediterranean. Adults and large individuals are generally found at high depths. The bathymetric range varies between areas and depends on two main elements: the ontogenic change in experienced habitat and the geomorphology of the bottom (Hidalgo 2007, Bartolino et al., 2008).

In the Alboran Sea, European hake is mainly found between 30 and 255 m along the Spanish coast and the Alboran Island where the most suitable nursery grounds are located (Muñoz et al.,2018).

2.2.4. Biologic and ecologic features

2.2.4.1. Life cycle

Along the life cycle of European hake, the different life stages occur at different bathymetric ranges (Hidalgo, 2007) (Figure 11). The female can carry from 110.000 to 350.000 eggs depending on their size (Fishbase). The embryonic development lasts only for a few days (Combs et Michelle, 1982). After the hatching, which takes place after two days (Hidalgo, 2007), the larvae are concentrated in the spawning grounds over the continental shelf. The larvae live a pelagic life for about a month (Bjelland et Skiftesvic, 2000). During this pelagic phase, they remain passive and are carried by currents. From 8 mm in length, larvae swim actively towards nursery areas (Alvarez et al., 2004).The larvae are, thus, planktonic and their metamorphosis into juvenile takes place after two months on average. After the pelagic phase, they become close to the bottom at 3cm in length, where they make the transition to demersal life before joining the nursery areas (Belloc, 1929). Nursery zones are usually located on muddy bottoms between 75 and 120 m of depth (Oliver et Massutí, 1995, Maynou et al., 2003). At the juvenile stage, hake stays on the mud flats, has a size of 31 cm, it migrates to the coast up to 25 m, while the adults return to high depths up to 1000 m (Cohen et al., 1990).

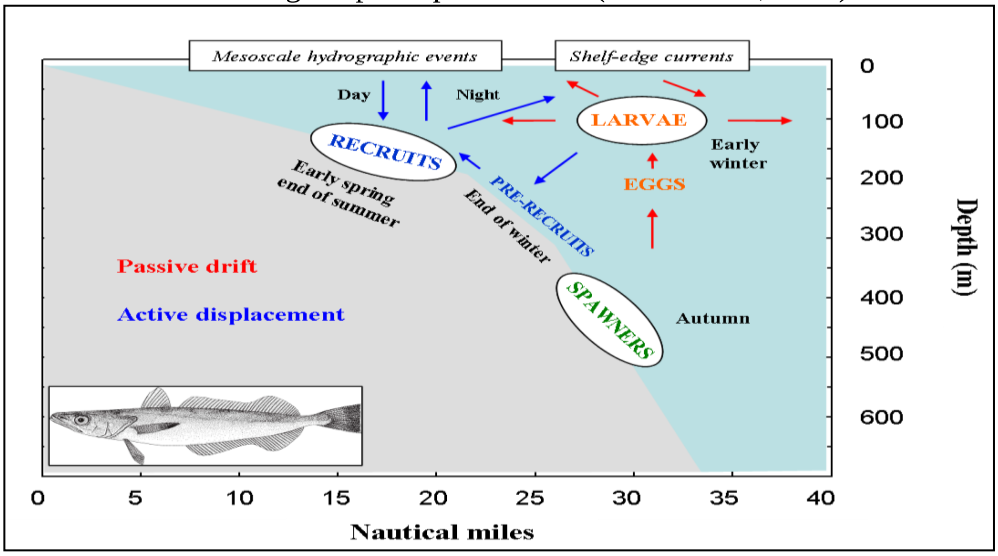

Figure 11. Seasonal bathymetric distributions fot European hake (adapted from Hidalgo,2008).

2.2.4.2. Reproduction

In the Mediterranean, hake populations seem to have a protracted reproduction throughout the year. This pattern is supported by many studies (e.g. Papaconstantinou and Stergiou, 1995, Belcari et al.,2001, Recasnes et al.,2008). *Merluccius merluccius* is generally considered as a batch spawner with asynchronous oocyte development that releases yolk oocytes in several batches over a protracted period during each spawning season.

The spawning occurs at the shelf break zone all the year with two high peaks depending on the area. While in the Western Mediterranean spawning peak in spring and summer, it peaks mainly in February and June in the Alboran sea (CGPM,2018).

The length of first maturity or L_{50} stands for the length at which 50% of the fish are mature. It is widely studied for fish population because it is considered as an indicator of species vulnerability. Hake's length of first maturity, in the Western Mediterranean is estimated by different authors between 22-32 cm for males and 30-39 for females. In terms of age, it corresponds to 3 and 4 years respectively. In the Alboran Sea, the L_{50} is 26 cm and it estimated for combined sex. However, female and male mature at different size and probably at different ages with male's L_{50} lower than female (Hidalgo, 2007). A mean of L_{50} have been established by Ifremer (2016) for males and females in the Mediterranean. Males reproduce for the first time at 27 cm and females at 37 cm (Ifremer, 2016).In the Alboran sea, L_{50} for combined sex is estimated to 13.55 cm(CGPM,2018)

2.2.4.3. Recruitment

In marine fish, recruitment is recognized as fundamental to population dynamics and fluctuations in stock size. Indeed, recruitment is the amount of fish added to exploitable stock each year due to reproduction and or migration to the fishing area (Hidalgo, 2007). Abundance of juveniles and recruits can fluctuate year to year or even across seasons (Hidalgo et al., 2008, Goikoetxea and Irigoien, 2013). The success of recruitment process is linked to environmental conditions and the existence of nursery areas where hake recruits and pre-recruits are grouped in patches.

As regard the European hake in the Mediterranean, recruitment of juveniles to the fishing grounds is almost continuous throughout the year, but there is a large seasonal variability in the abundance of recruits at different spatial scales. Generally, hake recruitment has two peaks, one in spring and another on autumn (Maynou et al., 2003). These two periods of recruitment probably correspond to two spawning peak periods (Recasens et al., 1996). In the Alboran Sea, high abundance of recruits is regularly observed in spring and autumn (GFCM, 2018). At the bathymetric range, high abundances of hake are concentrated mainly between 100 and 200 m (Rey et al., 2004)

Based on joint assessments performed every year, recruitment size is reported as 14.5 cm in all the GSAs of the Alboran Sea. Furthermore , stock assessment results, conducted by working groups of CGFM, have shown fluctuations on recruitment during the period 2007-2017 (Figure 13) over the whole series, increasing in the two lasts years (GFCM,2018).

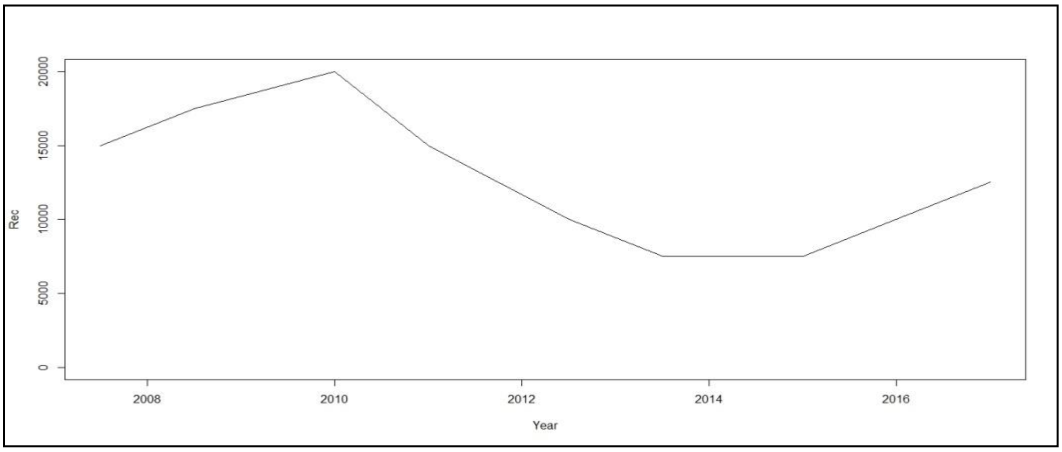

Figure12. Recruitment evolution in GSA 01 and GSA 03.

2.2.4.4. Growth

Growth is one of the most problematic aspects on hake biology in any of its areas of distribution and has motivated discussion and debate during decades due to its importance in the assessment process. Generally, for growth estimation, two main techniques are used, length frequencies distribution and otolith sections readings.

Based on the already mentioned techniques several models have been set to estimate different growth parameters. Thanks to one of those studies that were conducted by De Pontual et al., (2003), the debate on the growth of hake could be definitively resolved, resulting in a change from the paradigm of "slow growth" to that of "fast growth" of hake. Nowadays, it is assumed that hake is growing twofold faster than previously estimated and that five age classes are contributing to the fishing activity instead of ten.

In the Mediterranean, hake growth rate vary across areas. It has been reported to be 0.7-1.2 cm/month^{-1} in the Ligurian Sea (Orsi-Relini et al. 1989), 1.15 cm/month^{-1} in the Gulf of Lions (Morales-Nin and Aldebert ,1997), 1.25 cm/month^{-1} in the Adriatic Sea (Arneriand Morales-Nin , 2000), 1.2-2.5 cm/month^{-1}in the Catalan Sea and 1.53 in Tyrrhenian Sea cm/month^{-1}(Belcari et al., 2006). In addition, growth rates differ between sexes from the second year with higher values in favor of females (Garcia-Rodriguez and Esteban, 2002). In the Alboran Sea, the same growth parameters for combined sexes are used for both GSA01 and GSA03:

Table2. Growth parameters for European hake in the Alboran Sea (CFGM, 2018)

Model	Parameter	Value
Growth model	L (cm)	108
	K (yr$^{(-1)}$)	0.21
	t_0 (yr)	-0.115
Length weight relationship	a	0.006
	b	3.035

It is worth noting that increase of fishing effort over the past 50 years could have affected biological traits, including growth parameters (Hidalgo et al., 2009). Moreover, throughout the Mediterranean, this species inhabits heterogeneous habitats characterized by a wide range of biotic and abiotic factors that might induce adaptive changes in growth (Vitale et al., 2016).

2.2.4.5. Feeding behavior

Feeding habits of European have been described widely in the Mediterranean. Like other gadoid, hake is a generalist top predator fish with adapted buccal cavity and maxillaries to capture the prey (Philips, 2012). The composition of the hake's diet varies greatly throughout its ontogenic development. Its diet also changes with the season, and the bathymetry. During its early life stages (TL < 16 cm), hake consumes small crustaceans such as *euphausiacea* and *mysidacea*. Progressively, as it becomes larger, hake rely less upon crustaceans for sustenance, and consumes more and more fish until becoming exclusively ichthyophagous (Stagiouni et al., 2011).

Several seasonal differences are often observed in the diet, with fish such as *E.encrasicolus, C. macrophthalma, G. biscayensis* found to make up main stomach contents all year round, especially in winter. Prey diversity in the diet is greater in summer in correspondence to specific prey occurrence at a given area. Despite these differences, the main prey species in the diet are often found to be the same for all seasons, and namely *E. encrasicolus, C. macrophthalma*, *Processa* sp., *S. membranacea*. (Stagiouni et al., 2011). According to the same authors, the diet of hake can also vary with bathymetry. At shallowest depth preys are dominated by clupeid, while gadoid occur progressively as depth increased. Furthermore, it is believed that hakes feed in mid-water or near the surface making daily vertical migration which is more frequents for juveniles (Pillar, 1998).

In the western Mediterranean , precisely off the Iberian coasts, hakes' diet is also quite different over bathymetric range with small crustaceans (*euphausiids*, *mysids* and small natantian decapods) being dominant at continental shelf and fish (mainly *Myctophidae*) being the main prey on the slope (Cartes et al.,2004).

2.2.5. Fisheries

European hake is a target of demersal species of the Mediterranean trawlers, long lines and gillnets fleets. However, in the Alboran Sea, it is mainly exploited by trawlers.

In the North Alboran Sea, bottom trawl is the most important fishing gear in terms of landings and fishing effort applied on both the continental slope and shelf to depths of 900 m (Camiñas et al., 2004). For the all fleet (artisanal gears not included), landings of hake by trawlers represented in 2017 approximately 91 % of the total landings, followed by small scale fisheries (GFCM, 2018). The trawling fleet in this area is composed of an average of 141 boats (varying from 133 to 150), averaging 34.9 GRT and 175.8 HP (Table 3). The port of Almeria hosts the highest number of boats with an average of 40 units. The fleet with the largest GRT corresponded to the port of Garrucha (55.3 t), followed by the port of Motril (44.7 t) by that of Almeria (43.1 t). Engine power was correlated to the size of the fishing vessel. Highest engine power was associated with those vessels based in the port of Garrucha (289.8 HP), Almeria port (205.7 HP) and Motril port (190.7 HP) (UNEP, 2014).

Table 3. Fleet characteristics of GSA 01 (UNEP, 2014)

Port	Gross Register Tonnage (t)	Engine power (HP)
Garrucha	55.3	289.8
Motril	44.7	205.7
Almeria	43.1	190.7

In the GSA03, the main landings are also produced by trawlers representing almost the total landings. The Moroccan trawling fleet, named “Coastal trawling fleet” is geographically heterogeneous (GFCM, 2018). Indeed, the average power of trawlers registered is 338 HP varying from 150 to 675 HP for an average capacity of 53 GRT, ranging from 21,46 and 138,55 GRT, and an average age of 24 years (INRH, 2018, UNEP,2014). Trawlers vessels are based in three main ports Nador (62.6%), Al Hoceima (23.2%), and M´diq (14.2%) (Table 4) .The port of Nador is the most important in terms of *M. merluccius* production (94%) and with regard to the fishing effort (91%) in 2017.

Table 4. Fleet charcteristics in GSA 03 (GFCM,2018)

Ports	Number of trawlers	Mean HP	Mean GRT
Nador	53	357	55
AL Hoceima	11	307	51
M’diq	30	200	28
Total	83	-	-

The fishing effort varies in both GSAs according to climatic conditions, abundance of the resource and fisheries management measures. During the period from 2009 to 2017 the effort evolution is similar between the two areas with trend dominated by an increase of effort during the period 2009-2011, a decrease between 2011-2014 followed by stagnancy at the end of the series (Figure 13). As the effort unit is different in the two areas, comparing fishing effort between areas can lead to misinterpretations.

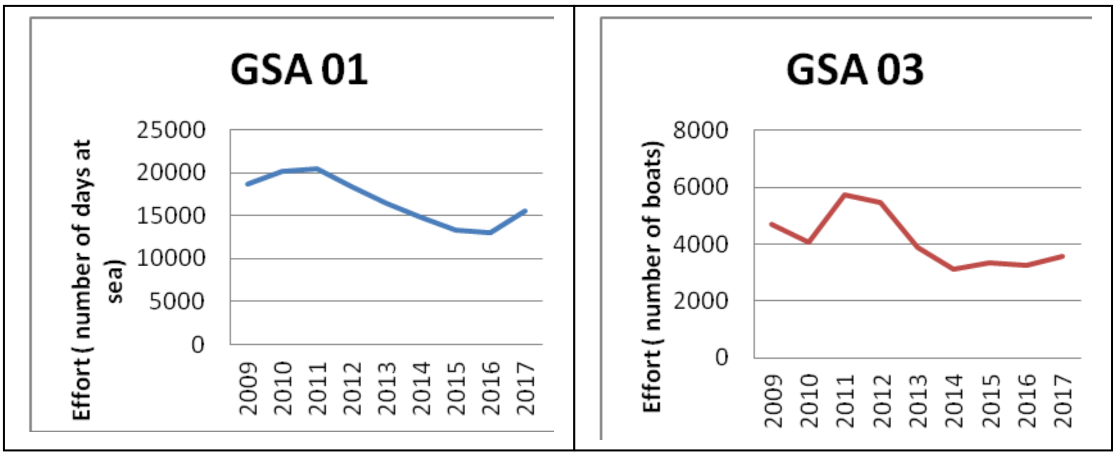

Figure 13. Effort evolution at GSA 01 and GSA 03.

Hake production in the Alboran Sea is also subject to fluctuations. In general, the landings follow the same decreasing trend in both GSAs, being more pronounced in the GSA 1 (Figure 14). The landings oscillated around an average of 350 t in GSA 01 and 150t in GSA 03 during the period 2009-2017. The time series are characterized by a slight increase between 2009-2011, followed by a sharp decrease from 2011 at GSA 01 but gradual from 2012 at GSA 03. The landings slightly increase again at the end of the series. The landings are higher in Spain than in Morocco with a difference that decreases along the time series (Figure 14).

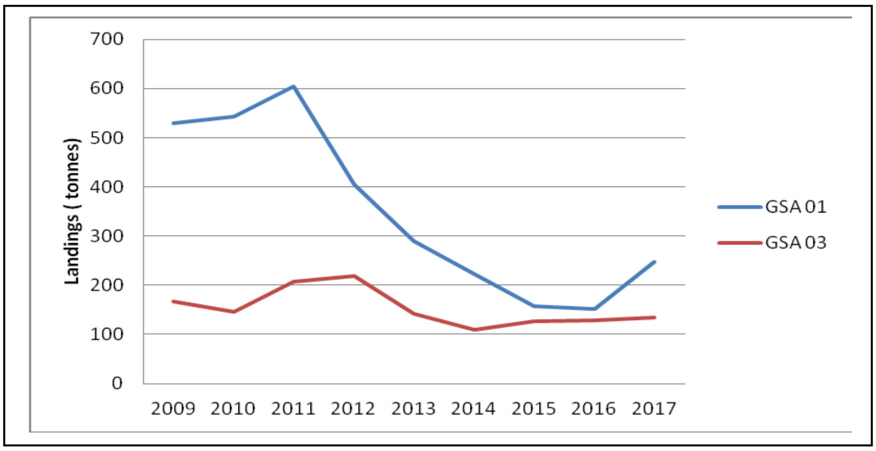

Figure 14. Landings evolution at GSA01 and GSA03

European Hake in the GSA 01 and GSA 03 as in many areas in the Mediterranean Sea, is overexploited (FAO, 2018).

Currently, national management actions exist. In GSA01, fishing is forbidden within upper 50 m. Time at sea is limited at 12 hours a day, 5 days per day (weekends are usually non fishing days). The fishing is allowed only with trawl having a mesh size of 40 mm or 50 mm for square and rhomboidal respectively. A power engine limitation to 316 KW or 500 HP is also established for the Spanish hake fishery (CFGM, 2018).

Concerning the GSA 03, the hake fishery is regulated by a ministerial order established in 25 November 2014. It is prohibited fishing under 1,5 nautical mile in the areas between Tangier (Cap Spartel) and Al Hoceima., under 2 nautical miles in the area between Al Hoceima and cap of three forks and under 3 nautical miles in the area between Cap of Three Forks and Saidia . The mesh size shouldn't be lower than 50 mm mesh stretched.

The minimum landing size is limited to 20 cm at both GSAs.

2.3. Datasets

In this work, dependent and independent data of European hake fisheries of Moroccan and Spanish Alboran were used, provided by Moroccan and Spanish scientists at INRH and IEO respectively.

2.3.1. Fisheries dependant data

2.3.1.1. Landing per unit of effort (LPUE)

The data used for LPUE estimation are based on the trawling fishery of European Hake in GSA 01 and GSA 03 given that more than 90 %of landings come from trawlers as mentioned previously.

For GSA 01, a total of 9 ports situated in the north Alboran coast are included. They were selected based on the availability and relevance of monthly time series of landings from January 2007 to December 2017. The concerned ports are (listed from west to east): Estepona, Marbella, Fuengirola, Málaga, Vélez-Málaga, Motril, Adra, Almeria, and Garrucha. The used data are provided by Center Oceanographic of Malaga (Spanish Institute of Oceanography, IEO). These landing time series were used to calculate standardized LPUE indices using fishing days as the effort unit: (kg/day).

For GSA 03, monthly time series from January 2009 to December 2017 for the Moroccan Mediterranean coast were obtained from the Regional Institute of Fisheries Research (INRH) of Tangier. They have been used to calculate the standardized LPUE indices using the number of vessels as effort unit: (kg/vessel). The considered ports are (listed from west to east): M´diq, Jebha, Al Hoceïma, and Nador. For this area, only ports with available data were kept for analysis.

In total, 13 ports are selected (Figure 15). The Spanish time series are the longest and encompass from 2007 to 2017 while the Moroccan time series extend from 2009 to 2017.

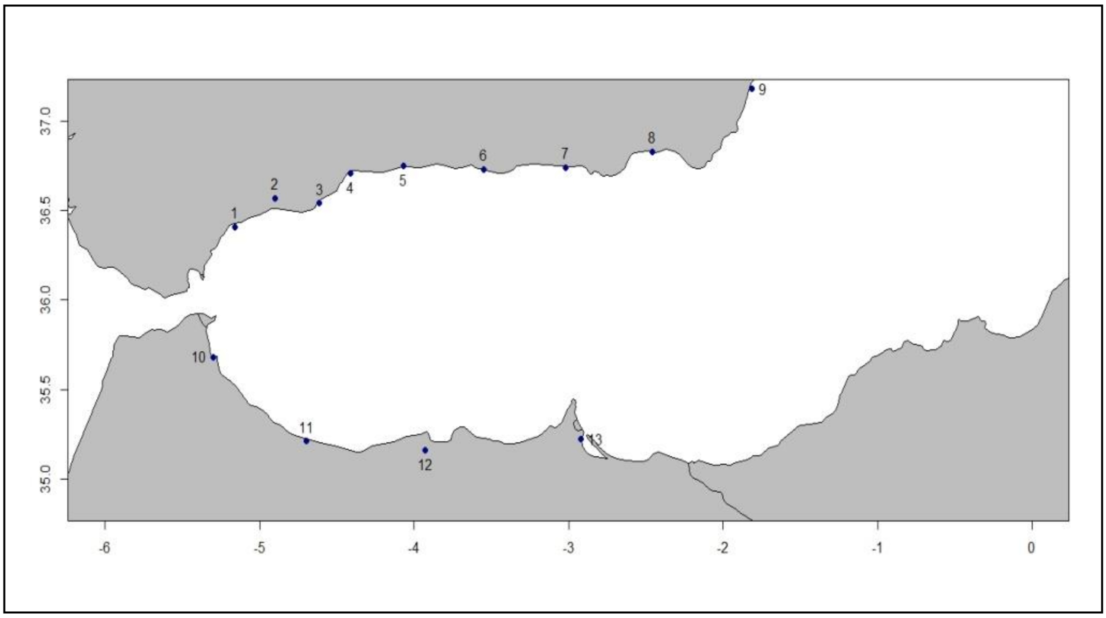

Figure 15. Map including ports considered (1) Estepona, (2) Marbella, (3) Fuengirola, (4) Málaga, (5) VélezMálaga, (6) Motril, (7) Adra, (8) Almería (9) Garrucha, (10) M´diq, (11) Jebha, (12) Al Hoceïma, (13) Nador

2.3.1.2. Length frequencies

Time series of the total length (TL, cm) (Figure 16) of European hake measured during the sampling programs in both countries have been collected.

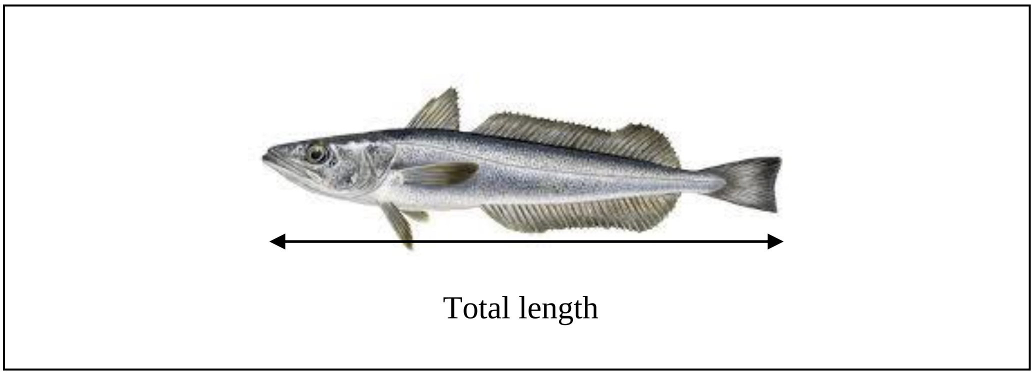

Figure 16. Hake total length measure.

For GSA 01 the time series are grouped by year quarter and extend from 2007 to 2017. The sampling data aggregate three ports: Fuengirola, Almeria and Aguilas. Regarding the GSA 03, the sampling was held at Nador port only where landings of hake are the highest. The time series are annual from 2009-2017. The collected data were organized and prepared for the required analysis.

2.3.2. Fisheries independent data

European hake abundance in the Northern Alboran data were collected in the framework of Trawl surveys in the Mediterranean (MEDITS programme) following the common protocol (Bertrand et al.,2002) during the Spanish survey carried out annually since 1994. These surveys are carried out during late spring or early summer following a stratified random sampling design based on different bathymetric strata(10-50m, 50-100m, 100-200m, 200-500m, and 500-800m), with number of hauls per strata proportional to its area. The used trawl net has a stretched mesh size in the cod end of 20 mm. Trawling duration is 30 min at lower depth and 60 min at are as deeper than 200m. For each haul, sampling information is recorded (e.g. Latitude, Longitude, depth, and species biomass and numbers among others).

For the southern Alboran Sea (GSA03), the demersal surveys are carried out twice a year, depending on the availability of the research vessel. The first one is conducted during spring and the second during summer. A trawl of 40mm Cod –end mesh size as opening is used for sampling following stratified random sampling design based on different bathymetric strata from the coast up to 800 m of depth. The bathymetric strata and the duration of trawling are identical to the GSA 1 survey, with a speed of about 3 knots (INRH). Data are available for the years 2006-2007 and from 2011 to 2015.

2.4. Analyses

Several statistical analyses were used to respond to each specific objective, selecting different method for different type of data.

All calculations and models were coded in R software (version R 3.5.1).

2.4.1. GAM analysis

To describe the time series of LPUEs of European Hake in every port in terms of annual trends and seasonal patterns General Additive Models (GAM, Hastie and Tibshirani 1990) were applied. The principle behind GAMs is similar to that of regression, except that instead of being parametric summing effects of individual predictors, GAMs are a sum of smooth functions. Functions allow us to model more complex (non-linear) patterns, and they can be averaged to obtain smoothed curves that are more generalizable without requiring a priori specification of underlying functional forms between dependent and independent variables. Thus, this method let the data to tell us the most plausible shape of the functional relationships.

In our model, we assumed additivity between the covariates year and month. The formulation used is:

$$LPUE_{i,t} = \alpha + s_1(\text{year}) + s_2(\text{month}) + e_t$$

Where $LPUE_{i,t}$ stands for the LPUE in the port *i* at the month *t* , $\alpha$is the intercept , $s_{1,2}$are non-parametric smoothing functions, which describe the annual and monthly variation of abundance index, e_t is the Gaussian distributed error term.

All models were checked for absence of autocorrelation (i.e. temporal dependence) in the residuals. For those models that showed autocorrelation in residuals, a mixed-effects GAM (GAMM) was applied including the autocorrelation structure in the residuals as follows:

$$LPUE_{i,t} = \boldsymbol{\alpha} + s_1(\text{year}) + s_2(\text{month}) + e_t(\mathit{CorrARMA})$$

The diagnosis of the autocorrelation and its order was performed using a correlogram (Auto Correlation Function, ACF plot). For those models that have shown correlation in a lag higher than 1, Akaike Information Criterion was applied as measure of goodness of fit to select the best model having the smallest AIC value.

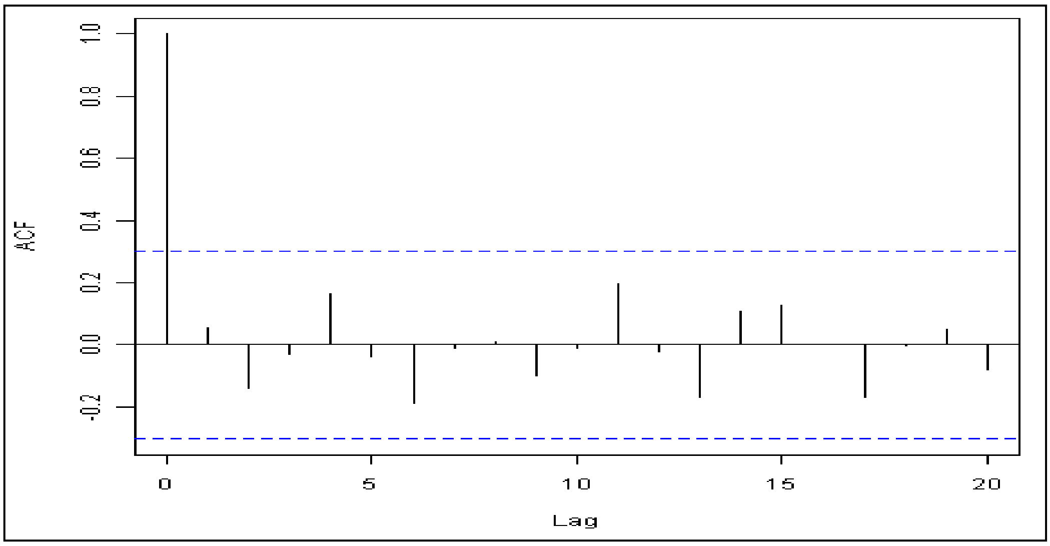

Figure 17. Example of an ACF plot.

2.4.2. *Dynamic factor analysis*

To identify underlying common trends or potential synchronic behavior among LPUE time series of the 13 ports, a Dynamic Factor Analysis (DFA) was used (Zuur et al., 2003). DFA is a dimension-reduction technique especially designed for time-series data. DFA can be used to model short and non-stationary time series in terms of common patterns and explanatory variables. That is, DFA models a set of *n* observed time series as a linear combination of *m* common trends, covariates and error terms due to temporal variability. The mathematical formulation of this model, in matrix notation, considering only the common trend and noise can be written as following:

$$y_t = \mathbf{Z}\,\alpha_t + \mathbf{e}_t$$

Where $\mathbf{y}_t$ is a $N \times 1$ vector containing the values of the N time series at time t. α_t represent the values of the M common trends at time t, and $\mathbf{e}_t$ is a $N \times 1$ noise component, which is assumed to be normally distributed with mean 0and covariance matrix $\mathbf{R}$. The $N \times M$ matrix $\mathbf{Z}$ contains the factor loadings and determines the exact form of the linear combinations of the common trends. By comparing factor loadings with each other, it can be inferred which common trends are important to a particular response variable and which group of response variables are related to the same common trend. The trends represent the underlying common patterns over time.

In our study we used two DFA models, the first one, were applied to observed LPUE time series of every port without any transformation as following:

$$LPUE_{t\,=} = \mathbf{Z}\,\boldsymbol{\alpha}_t + \mathbf{e}_t$$

Note that in our case explanatory variables are not considered.

In the second model, to make sure to underline only the seasonal common patterns without being confounded by long-term trends, we applied a GAM model beforehand to remove the long-term trends and to extract only the seasonal component contained in the residuals of the applied GAM. The model, hence, is written as:

$$GAM_{residuals\,(t)=} = \mathbf{Z}\,\boldsymbol{\alpha}_t + \mathbf{e}_t$$

The correlation of errors can take different structures of the matrix R: i) same variance and no covariance (diagonal-equal), ii) different variances and no covariance (diagonal-unequal), iii) same variance and covariance (equalvarcov) and iv) different variance and covariance (unconstrained). To take in account this specifications all possible structures were fitted for the 13 time series (for both DFA models), including 1 to 3 common trends. The 12 obtained models were compared using the Akaike's information criterion. For the best model (i.e. with lowest value of AIC value), common trends, factor loadings were calculated and visualized.

All the calculations were done using the MARSS package (Holmes, 2012) designed for DFA analysis under R. To make easier the calculations and their interpretation, we standardized LPUE time series at the same scale by calculating and standard deviation for every time series and, then, for each observed value of the series I subtract the mean and divide by the standard deviation.

2.4.3. Curves of density

To present, and visually compare length distributions, density curves were applied. A density curve is a graph that shows probability. The area under the density curves equal to 100 percent of all probabilities. In our case, we used the "ggrids" and "ggplot 2" package in R to get density curves that describe and plot the length distribution of hake among areas and years.

2.4.4. ANOVA model and Kolmogorov–Smirnov test

To statistically test significant difference in the means of various groups ANOVA (Analysis of Variance) was used. We used a two way ANOVA to detect significant differences on mean length of European hake among areas and years. That is, we used ANOVA to examine spatial and temporal variability of mean length of sampled hake. The factors "Year" and "area" were treated as fixed and orthogonal factors. The factor "Years" has 8 levels from 2009 to 2017 while the factor area has only two levels "Morocco" and "Spain". ANOVA assumptions were a priori checked and were not violated. When the ANOVA test was significant, *post hoc* analyses were conducted to indicate which length mean is different from the rest.

To compare the length distribution across years and within areas we also used Kolmogorov–Smirnov test. It is widely used to test if two arbitrary distributions are the same. It can be used to compare two empirical data distributions, or to compare one empirical data distribution to any reference distributions. It is based on comparing two cumulative distribution functions.

2.4.5. Spatial distribution metrics

To investigate potential similar and/or a/synchronic changes in distribution of European hake in the north and south Alboran and how distribution may change with time, the available spatiotemporal information of scientific bottom trawl surveys was used to calculate spatial distribution metrics. Spatial indices of location (mainly centers of gravity, CG, in our case) in longitude, latitude and depth were calculated for hake each year at GSA 1 and 3 as described by Woillez et al. (2009) and using the R Geostast package in R software (R Core Team; 2014). CG is the mean location of a population and also the mean location of an individual fish taken at random in the field, considering that each data location was weighted by fish density. We also calculated the inertia (I), which is the mean square distance between such an individual and the CG, and describes the spatial dispersion on the population around its CG. The CG is calculated as, following:

$$\mathrm{CG}=\frac{\int xz(x)dx}{\int z(x)dx}$$

Where Z is sample values (density, dens) at locations x. The inertia, I, is calculated as the variance:

$$\mathrm{I}=\mathrm{Var}\ (\bar{x}) = \frac{\int (x-CG)^2 z(x)dx}{\int z(x)dx}$$

For each region (Morocco and Spain), linear models (LM) were fitted to the time series of longitude, latitude and depth of CG to asses temporal trends. To assess potential density-dependent changes in the distributions, LMs were also fitted to CG coordinates using annual mean density as covariate.

To compare the CG trends patterns between Morocco and Spain, we have explored Pearson correlation between the spatial descriptors in the two areas by applying correlation matrices. The coefficient of correlation is a measure that indicates to which extent our variables fluctuate together. A correlation indicates the extent to which those variables increase or decrease in parallel, that is synchronic variation. A indicates the extent to which one variable increases as the other decrease; asynchronic variation. We considered only significant correlations ($p<0.05$).

3. Results

3.1. LPUE monthly time series description

3.1.1. Spain

The deviance of the LPUE explained by the Generalized Additive Models (GAMs) models including ‘Year’ and ‘Month’ as covariates ranged between 8.74 % (in Garrucha) and 60.5% (Motril). The GAMs confirmed significant seasonal and inter-annual differences in all GSA01 ports except in Marbella, Adra and Garrucha, which did not show seasonal differences (Table 5)

Table 5. GAM results for GSA 01 including two covariates (‘Year’ and ‘Month’). EDF: EstimatedDegrees of Freedom, DE (%): Deviance Explained.

Port	Covariates	EDF	p-value	DE (%)
Estepona	Year	2.958	<<0.005	50.2
	Month	1.668	<0.005	
Marbella,	Year	2.9179	<<0.005	30.6
	Month	0.4979	>0.05	
Fuengirola	Year	2.959	<<0.005	50.3
	Month	1.556	<0.05	
Málaga	Year	2.887	<<0.005	41.5
	Month	1.978	<<0.005	
Vélez-Málaga	Year	2.974	<<0.005	58.7
	Month	1.830	<<0.005	
Motril	Year	2.985	<<0.005	60.5
	Month	1.402	<0.05	
Adra	Year	1.000	<<0.005	21.4
	Month	1.326	>0.05	
Almería	Year	1.9508	<<0.005	30.5
	Month	0.1691	>0.05	
Garrucha	Year	2.946	<<0.005	8.74
	Month	1.286	>0.05	

The inter-annual variation of mean LPUE showed a general pattern characterized by an increase between 2008-2010 followed by a linear decrease. The highest LPUE values were generally observed between 2008 and 2010 and the lowest values between 2014 and 2016 (Figure 19). All the ports followed this pattern except for Adra, which exhibited a decreasing trend along the time series. As regards the seasonal variation (Figure 18), two patterns were observed: i) a marked higher LPUE peak on February-August observed in Málaga, Velez Malaga and Motril, and ii) a weak seasonal peak from July-November observed in the western ports, Estepona and Fuengirola.

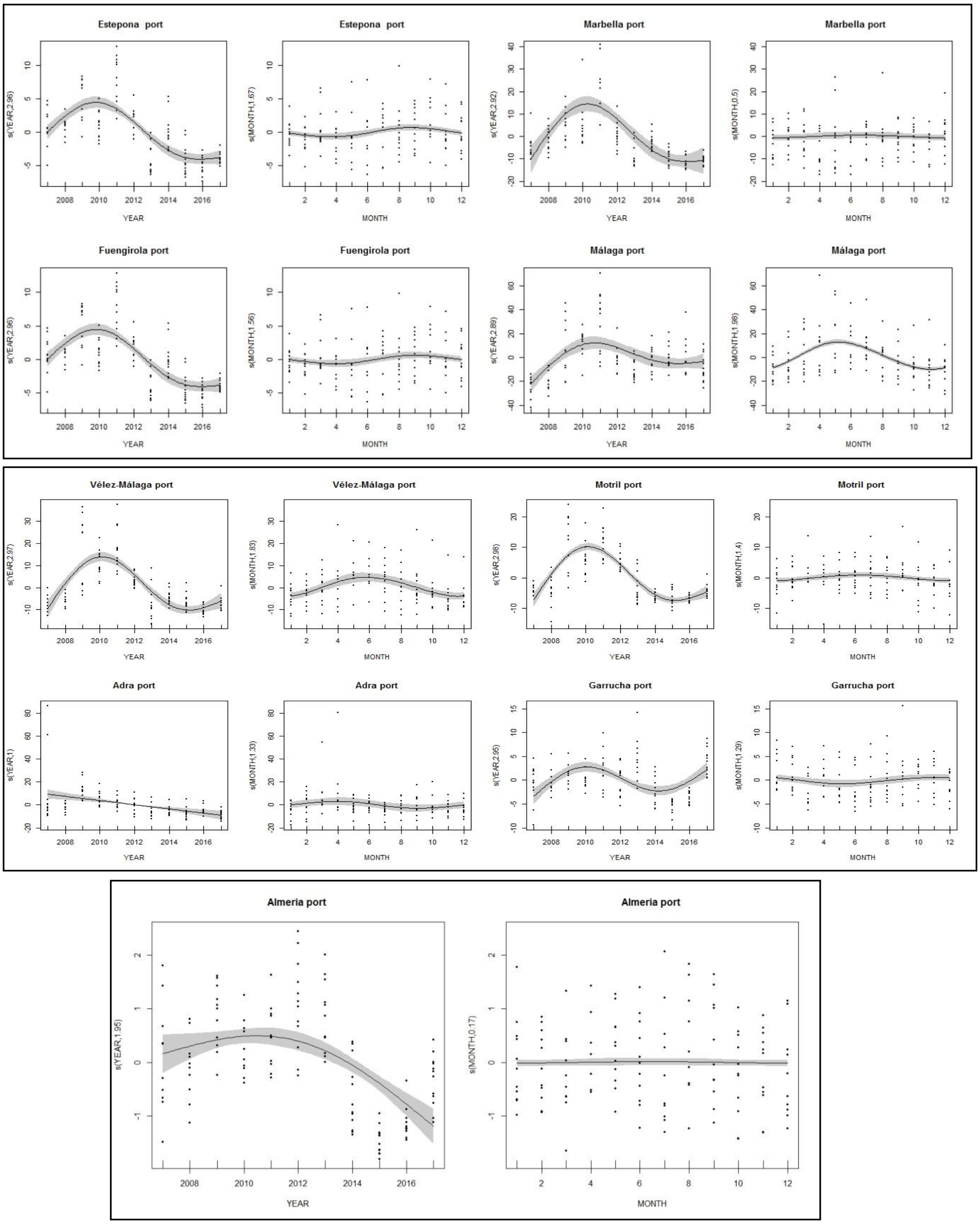

Figure18.Additive covariates (year and month) effect on observed LPUE for GSA01.

3.1.2. Morocco

The deviation LPUE explained by GAMs was generally lower compared with Spanish ports and ranging from 4.63 %(M'diq port) to 21.7% (Al Hoceïma port) (Table 6).The models revealed significant seasonal and inter-annual differences in LPUEs in most of GSA03 ports, except in Nador that did not show significant inter-annual differences, and Jebha that did not show significant seasonal differences.

Each port displayed a different inter-annual pattern. The GAM highlighted a higher LPUE values between 2012 and 2015 for M'diq and Jebha ports, and a decrease over time pattern at Al Hoceïma (Figure 19).

The monthly variability of LPUEs was heterogeneous among ports i) a peak in April-June at Al Hoceïma port, ii) a peak in January-April in M'diq and Nador. This seasonal pattern was not geographically segregated since Al Hoceïma is between M'diq and Nador.

Table 6. GAM results for GSA 03 including two covariates (year and month) .EDF: Estimated Degrees of Freedom, DE (%): Deviance Explained

Port	Covariates	EDF	p-value	DE (%)
M´diq	Year	2.464	<<0.005	19.5
	Month	1.739	<0.005	
Jebha	Year	2.77	<0.05	20.8
	Month	0.279	>0.05	
Al Hoceïma	Year	1	<<0.005	21.7
	Month	1.71	<0.005	
Nador	Year	1	>0.05	4.63
	Month	1.41	<0.05	

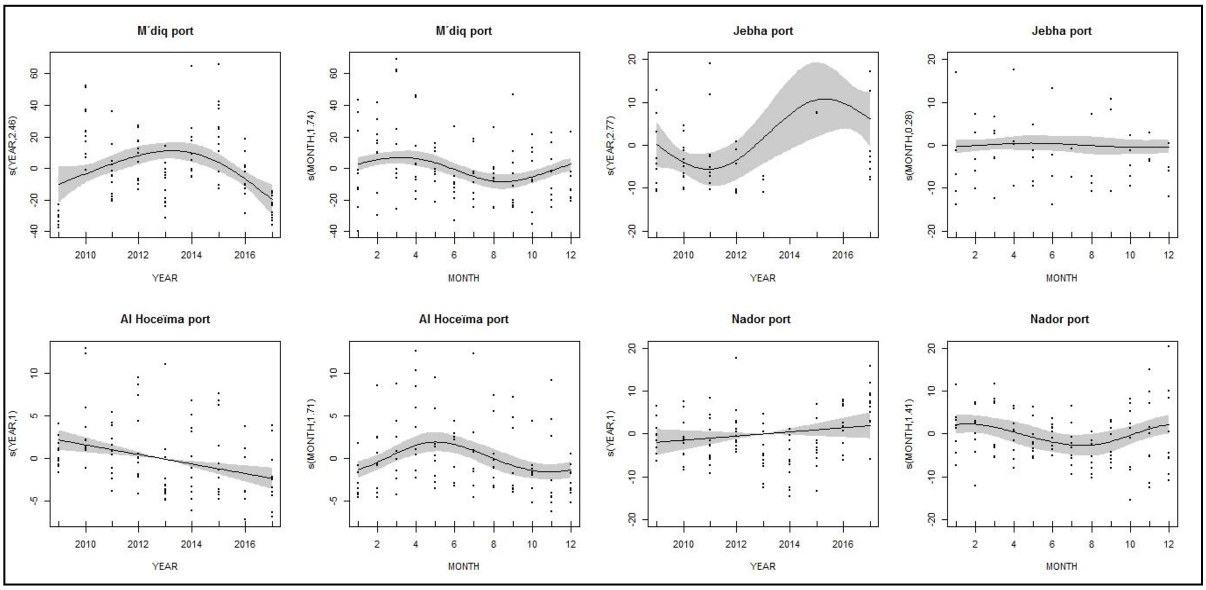

Figure 19.Additive covariates (year and month) effect on observed LPUE for GSA03.

3.2. Analyze of common trend on LPUE time series

Two sets of DFA models were used. The first one applied to LPUE time series without any modification. The second one was applied to LPUE time series after removing the long term effect that could hide seasonal effect applying a GAM analysis.

3.2.1. DFA with standardized time series.

A first DFA was applied to monthly time series of European Hake standardized LPUE (DFA1).In this set of analyses, the best DFA model had three common trends (m=3) and observation errors with different variance and covariance (R=unconstrained)(Table 7).

Table7.First four best models obtained by applying Dynamic Factor Analysis in LPUE time series. R; Matrix of errors; M: number of trends, AIC : Akaike Information Criterion (AIC) and Deta Akaik Information Criterion (Delta AIC).

	R	M	AIC	Delta AIC
DFA 1	Unconstrained	3	2622.498	0
	Diagonal and unequal	3	2629.786	7.28
	Unconstrained	2	2686.317	63.81
	Diagonal and unequal	2	2690.384	67.88

The first common trend displayed a general decreasing trend with a seasonal pattern characterized by long period (half year) of high values between February and September. The factor loadings indicated that this pattern was mainly associated to the Spanish ports, with higher association in the western. In Morocco, only Al Hoceïma followed this pattern albeit with a low factor loading value.

The second trend showed a fluctuating pattern until 2013 when it showed a continuous increasing trend. At seasonal level, LPUE marked a weak peak between May and June followed by an increase towards the end of the year. This trend was associated to Marbella, Fuengirola, Malaga, Vélez Malaga, Jebha and Nador with positive factor loadings values. Adra, Almeria, and M'diq were associated negatively to this trend. All the factor loadings were < 0.2.

The third trend was fluctuating over all the time series more than the two others. It showed a seasonal peak between May and September. This trend was associated to Fuengirola, Almeria and highly associated to Garrucha port. All Moroccan ports displayed negative factor loadings except Nador that was positively associated to this trend.

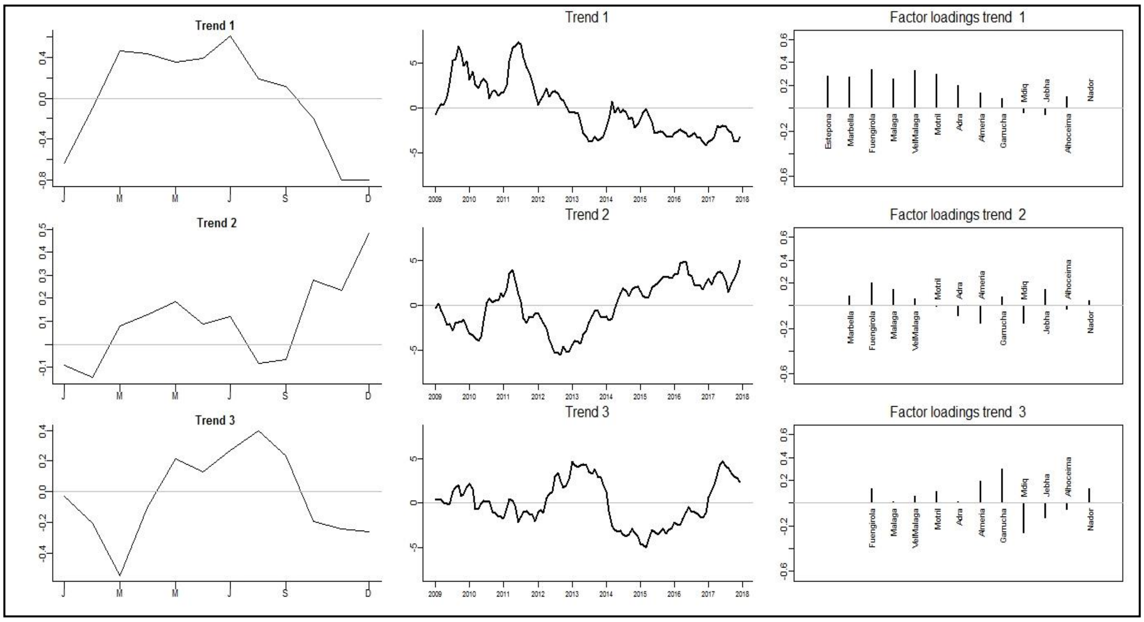

Figure 20. Results of Dynamic Factor Analysis (DFA1) for landings per unit effort (LPUE) time series with seasonal and factor loadings. All y-axis are unitless.

3.2.2. DFA without long term trend

An additional DFA was applied to monthly LPUE time series after removing the long-term affect and keeping only the seasonal component (DFA2). The results demonstrated that the best DFA 2 model had two trends (m=2) with an error matrix of same variance and no covariance (R= diagonal and unequal) (Table8).

Table8. First four best models obtained by applying Dynamic Factor Analysis. R; Matrix of errors, m: number of trends, AIC: Akaike Information Criterion and Delta Akaike Information Criterion (Delta AIC)

	R	M	AIC	Delta AIC
DFA 2	Diagonal and unequal	2	3011.034	0
	Diagonal and unequal	3	3013.118	2.08
	Unconstrained	2	3036.148	25.11
	Unconstrained	3	3044.598	33.56

The first common trend is roughly stable between 2008-2012 and then going down till the end of the time series. The seasonality of LPUE was shaped by a peak in spring between May and June. Factor loadings associated to this trend, indicated differences between northern Alboran which were highly influenced by this trend, and Southern Alboran Sea that showed lower factor loading values and even negative in some ports (Figure 21). Moreover, this trend is more linked to the Eastern Alboran than to the Western part. This fact is clearer for the Spanish ports where Eastern ports showed higher values of factor loadings.

The second common trend described an early high peak of LPUE between January and March, decreasing gradually until the end of the year. The factor loading evidenced differences between Eastern and Western Alboran Sea. In fact, only the ports located in East followed this trend with lower factor loadings values for the Moroccan ports, which is probably due to the missed values in the monthly LPUE series.

These two long term trends are quite similar to the first DFA applied on standardized time series.

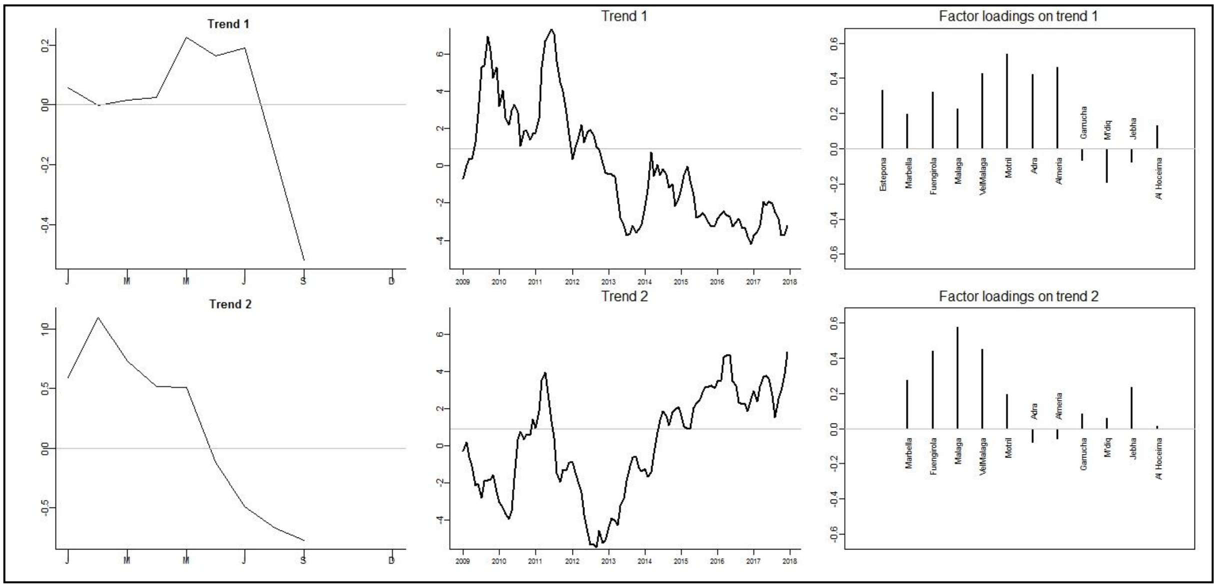

Figure 21.Results of Dynamic Factor Analysis (DFA1) for landings per unit effort (LPUE) time series with seasonal, long-term trends and factor loadings. All y-axis are unitless.

3.3. Analysis of spatiotemporal variation of of centers of gravity of hake

3.3.1. Spain

The center of gravity (CG) of European hake distributions using seasonal scientific Spanish Moroccan surveys showed clear inter-annual fluctuations in longitude, latitude and depth. For the north Alboran (Figure 22), CG in latitude and longitude showed similar fluctuations that were density dependent with distributions shifted towards northeast in years of higher density ($p<0.05$, table 4).Only the CG in latitude showed a significant temporal trend ($p<0.05$).

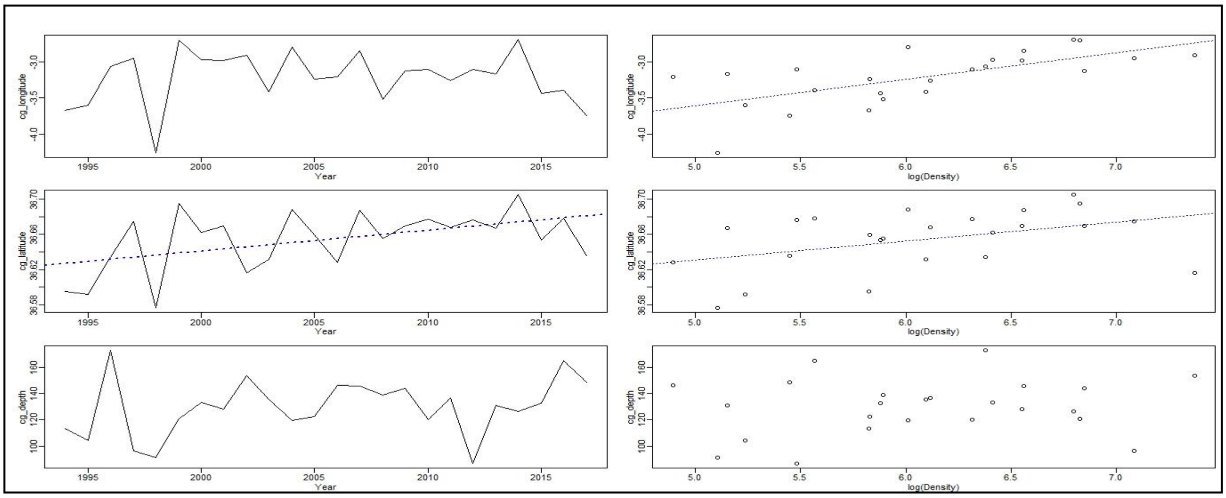

Figure 22. Time series of changes in centers of gravity of EH in longitude, latitude and depth. For GSA 01,linear models show significant effect of density ($p < 0.05$,blue dotted lines) for CGs in latitude (R^2=0.18) and longitude (R^2=0.44), and significant ($p<0.05$, R^2=0.23)temporal trend in latitude.

3.3.2. Morocco

The temporal variation of the spatial distribution EH in the Morocco are described by the CGs is also varying over time (Figure 23).However, no significant temporal or density-dependent effect was detected (Figure 23), likely due to the small size of data (n=8 years).

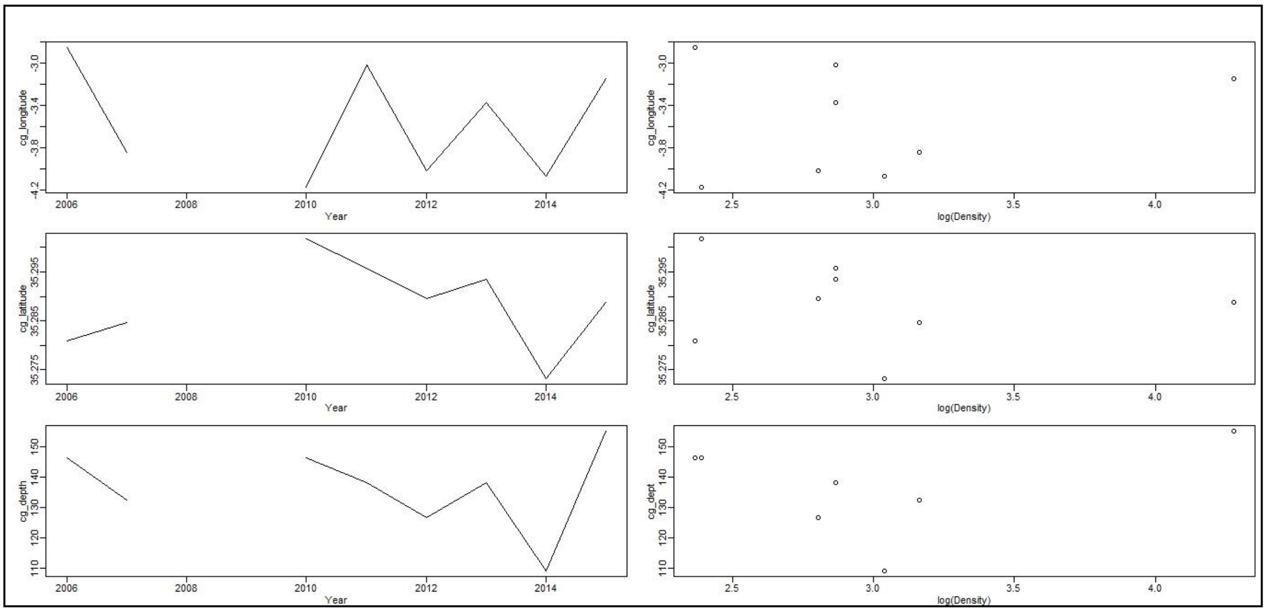

Figure 23.Time series of changes in centers of gravity of EH in longitude, latitude and depth for Morocco

Comparing CG longitude of EH in Morocco and Spain using Pearson correlation matrix (Figure 24), certain dependences emerge between Spanish and Moroccan distributions besides the patterns already observed in each country (Figures. 22 and 23). First, an opposite pattern in longitudinal distribution was observed between countries; that is in the years when the distribution in Spain was shifted towards northeast (i.e. high densities in Spain), distributions in Morocco were shifted towards west. However, the significance of some of the correlations are conditioned by the sample size available. Second, there is a high negative significant correlation between both longitude and latitude of centers of gravity in Spain and depth of centers of gravity in Morocco; that is, southwestern movements in Spain trigger a deeper distribution in Morocco (Fig. 25). The similar pattern is reflected by high negative significant correlation (r =-0.82) between CG longitude in Spain and CG latitude in Morocco, suggesting that a westward shift of hake in GSA 01 is associated to a shift to lower latitudes of CG hake in GSA 03 approaching the coast (i.e. shallower distribution).

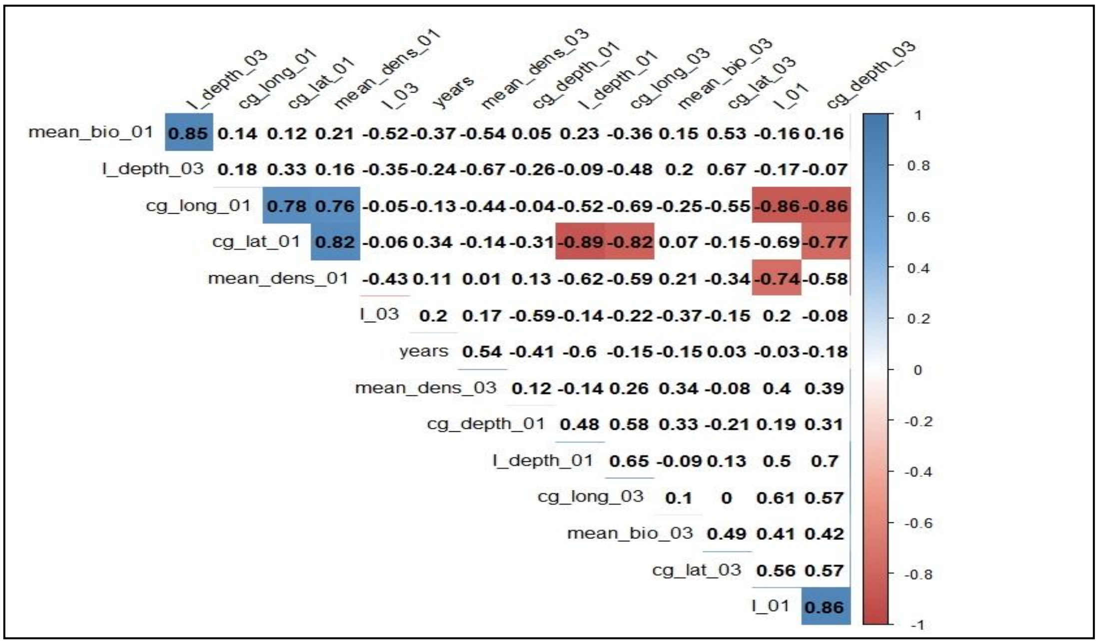

Figure 24. Pearson correlation matrix for CG coordinates among time and density levels EH population in the Alboran Sea for Spain (parameters ending with 01) and Morocco (parameters ending with 03), with significance positive correlation parameters shaded in blue and negative are in red. Note that number of years available for Morocco, conditioned the number of observations in this matrix (n=8).

3.4. Analyze of monthly size frequencies of landings per port

3.4.1. Spain

3.4.1.1. Seasonal distribution

The length distribution of European hake showed a seasonal variability in the Spanish Alboran Sea (Figure 26). In the first quarter (January-April), distribution was remarkably composed smaller individuals compared to the rest period of the year. In contrast, higher individuals were recorded in the fourth quarter while the second and the third showed intermediate sizes associated to growth and seasonal progression of the cohort. This evidences that the European hake in GSA 01is mainly composed by a main spawning event and consequent recruitments along the year, with recruitment arriving to the fishery autumn-winter. In the fourth quarter, the two consecutive annual cohorts can be observed in the length distribution.

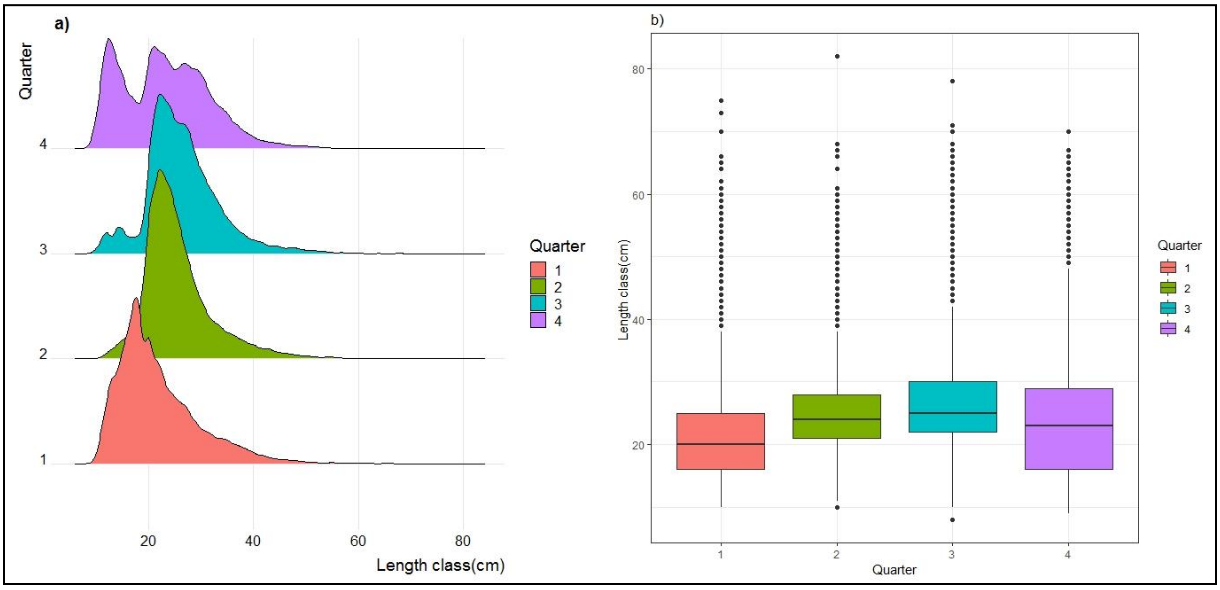

Figure 25. Density (a) and box plots plot (b) of length distributions (cm) by quarter during 2003-2017 in Spain.

3.4.1.2. Inter-annual distribution

Considerable inter-annual variation in the length distribution was observed at the beginning of the time series with smallerindividuals. This variation is less marked from 2010 on. The most noteworthy year is2006 with extremely abnormal lower individuals (small recruits) and no juveniles and adults observed in the fishery(Figures27and 28).Also, year 2010 showed an unusual distribution of hake length with a symmetric curve having higher mean length.

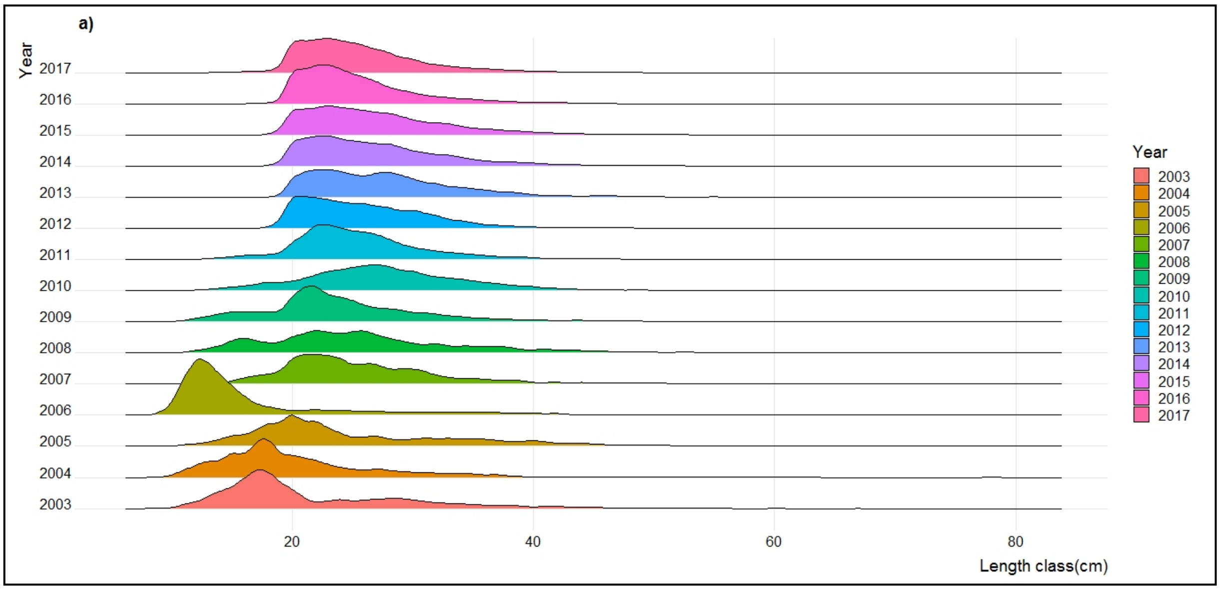

Figure 26: Density plots of total length (cm) distribution by year at Spain.

The length distribution represented by the density plot indicated that the mode of the curve is increasingly shifted towards lower length classes with L_{max} getting lower and lower over years (Figure 27).

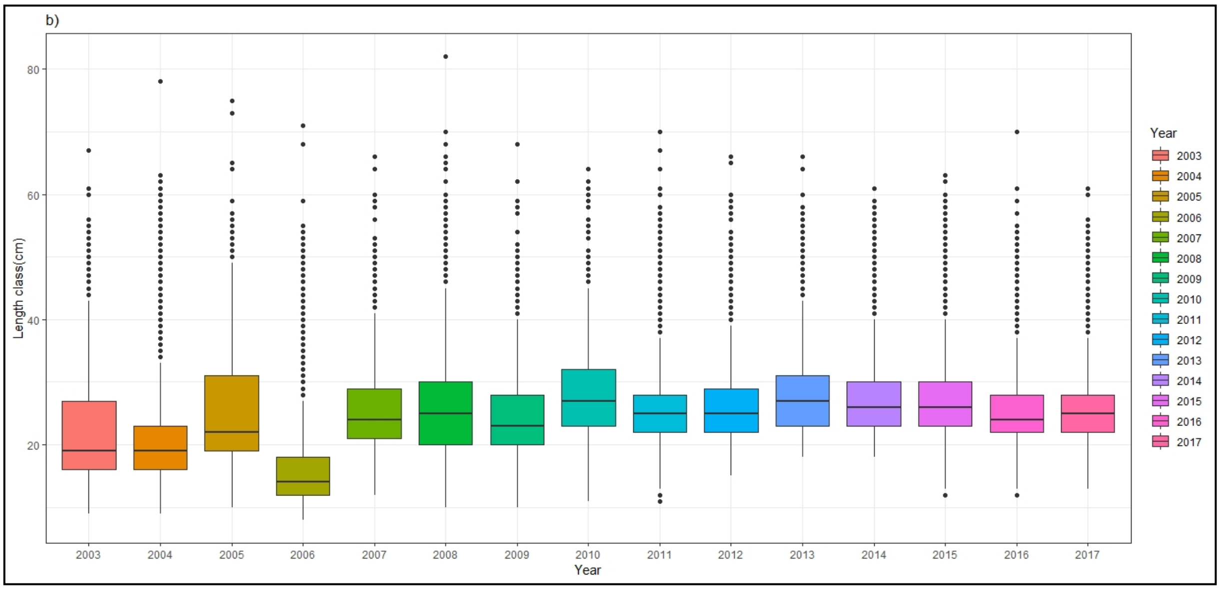

Figure 27. Box plots of total length (cm) distribution by year at Spain.

3.4.2. Morocco

Analysis of Moroccan length distributions showed increasing pattern of individual sizes of population at the beginning of the time series until 2009 followed by a continuous decreasing in the rest of the series (Figures 27 a, b).The asymmetry of density plots and thus, higher contributions of larger individuals was observed in Morocco (Figure 27).

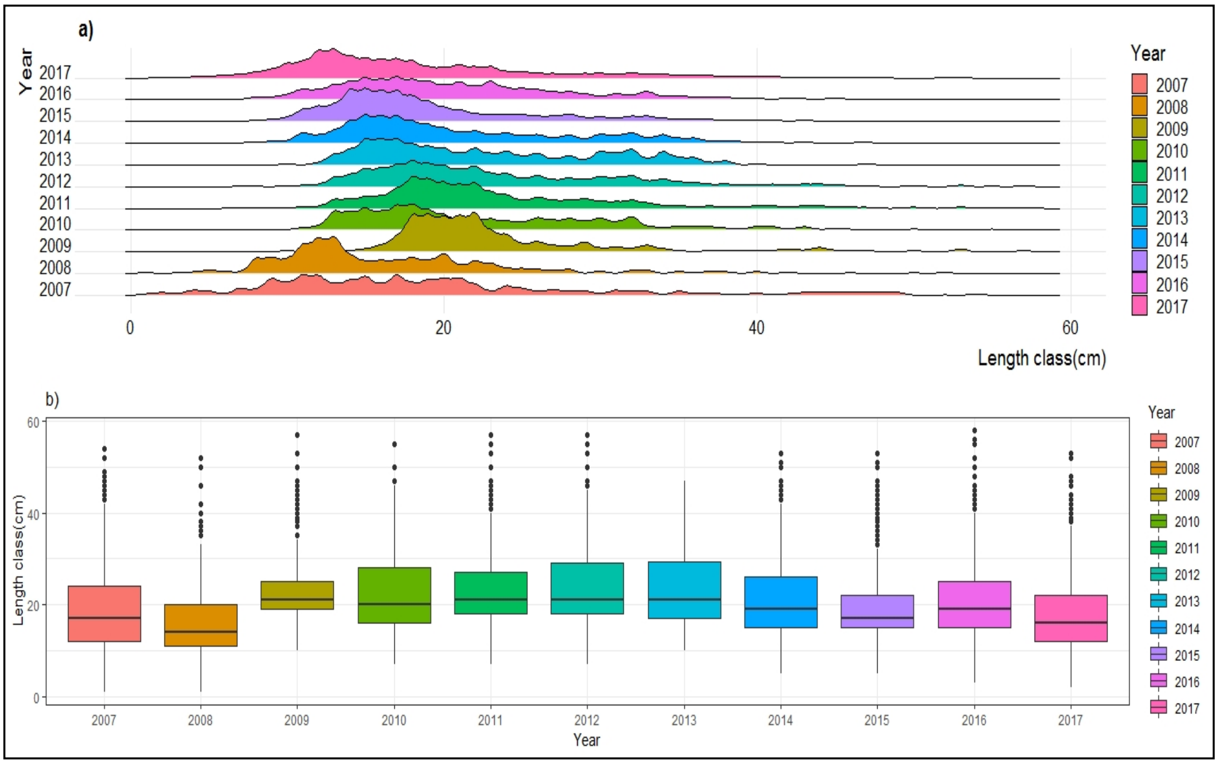

Figure28. Density plots (a) and box plots plot (b) of mean total length (cm) distribution of EH by year at Morocco.

3.4.3. Comparison

The two ways ANOVA test used to compare distributions between Morocco and Spain over time have shown significant differences among areas and years (Table9). The pair-wise post hoc test demonstrated that all the means are significantly different. The size distributions were generally higher in Morocco except for the years 2008, 2015 and 2017. Another difference worth noticing is the stability of length distribution in Spain at the end of the time series while mean size in Morocco was progressively decreasing towards recent years.

Table 9.Analysis of the effects of Area (fixed) and Year (fixed and orthogonal), on the mean total length

Source of Variation	DF	Mean length		
		MS	F	P_value
Area, A	1	312099	6381.7	<<0.001
Year,Y	10	68603	1402.8	<<0.001
A*Y	10	42713	873.4	<<0.001
Residuals	656055	49		

of European hake applying an ANOVA. DF: Degrees of Freedom, MS : Mean Squares, F; F ratio.

The length distribution of European hake were significantly different among years and across the two areas (Kolmogorov–Smirnov test t p-value <0.001). During the period 2007-2010 the density plot of frequency distribution for Spain were more shifted towards lower lengths compared to Morocco. Then, this shift appeared in Moroccan density plot while in Spain remained approximately stable till the end of series.

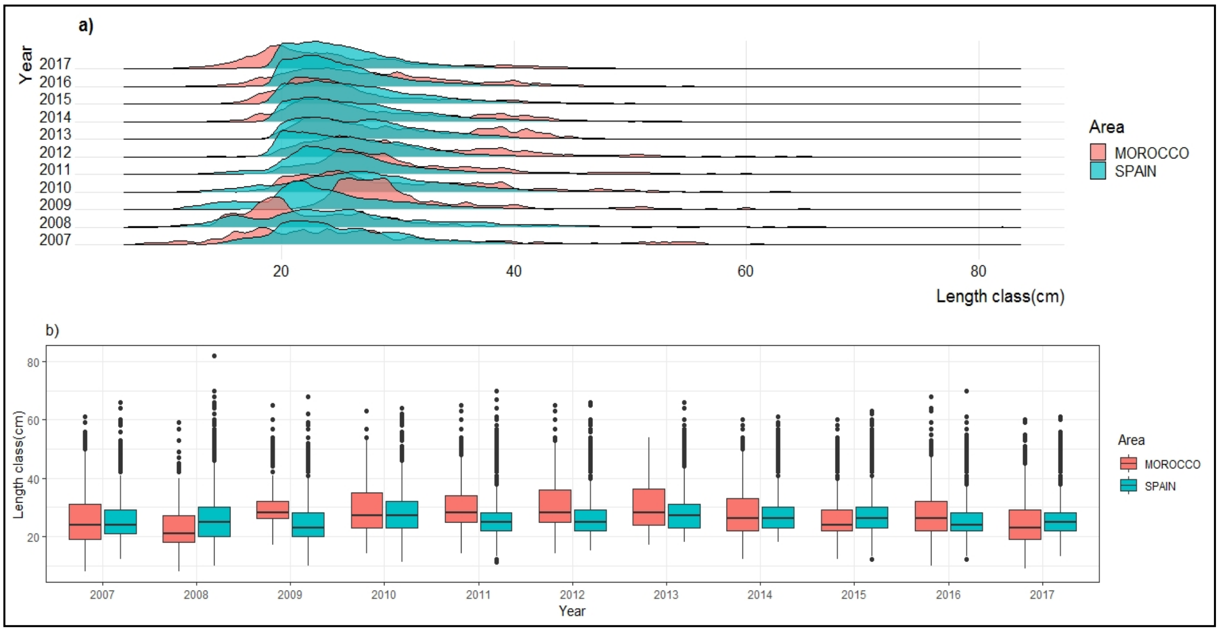

Figure 29. Density plots (a) and box plots plot (b) of mean total length (cm) distribution of EH by year at Spain(blue) and Morocco (red).

4. Discussion

The different data and methodologies used in this work allowed to shed light on the spatial dynamics of European hake populations at the Alboran Sea through a detailed research on the (di)similarities and (a)synchronies between the north and south part of this transitional sea. Outcomes of all methodologies were in agreement suggesting that there is a spatio-temporal variability on hake fishery indices showing alternating phases of connections and isolation between potential north and south hake sub-populations that depend primary on the dispersive phase of life stage of fish. Our results can be generally synthetized in the following patterns: i) a general differentiation between the local dynamics at the north and south Alboran, ii) a secondary but relevant similarity within eastern and western ports, and ii) certain asynchronic behavior present in the spatial distribution of juvenile hakes at nursery areas between north and south Alboran Sea.

Similarities and contrasting differences were observed in the clear inter-annual and seasonal variability of LPUE of hake in both GSA 01 and GSA 03. In GSA 01, inter-annual variability is shaped by one main common pattern observed in all the ports with the highest LPUE values between 2008 and 2010 and the lowest values between 2014 and 2016. This pattern mimics that reported in the recruitment index of the working group reports of European hake assessment which usually combine GSA 01 and GSA 03 data (GFCM, 2018; Figure13). This indicates that there is high influence of LPUEs in Spain in the recruitment estimates as it has been observed in the whole Mediterranean Sea (Colloca et al., 2013, Hidalgo et al., 2008, 2009) and also observed size distributions available for this study. In GSA 03, by contrast, the inter-annual pattern shows a high spatial heterogeneity with each port, displaying a different inter-annual pattern. This could be due to a different fisheries pattern, different dependence upon recruitment for each port or higher spatial heterogeneity on the southern sub-populations compared to the north one. Indeed, contrary to GSA 01, LPUE time series does not seem to be related to the recruitment estimates derived from the assessments done by GFCM (GFCM,2018) (Figure 13). This might be explained by the fact that the contribution of Moroccan catches to estimated recruitment indices is comparatively lower and consequently the fluctuations are hidden by the higher volume of Spanish catches; at least, for the landings time series that we used in this work (2009-2017).

At seasonal scale, LPUE variability has shown several peaks in both shores of Alboran suggesting a spatial segregation of seasonal dynamics. In GSA 01, two main peaks have been observed. At Málaga, Vélez Málaga and Motril ports (center of the Alboran Sea), highest values of LPUE occurs between February and July, while other peak is observed late in summer and autumn in the western ports at Estepona and Fuengirola. By contrast, Adra, Almería and Garrucha ports that are towards the east, does not show a significant seasonal pattern. Similarly, in GSA 03, two seasonal peaks have been highlighted. The first one takes place from late winter early spring in M'diq and Nador. The second one from the end of spring early summer at Al Hoceïma (center Alboran Sea), consistent with that afore-described in Málaga and Vélez-Málaga ports in Spain.

In line with GAM analyses, DFA also confirmed the seasonal and inter-annual variability of LPUE in the whole Alboran context. DFA model (after removing the annual component; DFA2) is considered to be more pertinent since it allows focusing in the intra-annual pattern. This model underlined two common trends. The first trend peaking between March and June is only associated to the north of Alboran. The second trend reaching its peak between January and March was mainly associated to western ports of Alboran, both of Morocco and Spain. DFA then brought out two spatial segregations. North-south segregation affiliated to the first trend and a secondary west-east segregation trigged by the second trend. Combining the results obtained by DFA and GAM analyses, we can synthetize our results as follows. On the one hand, LPUE interannual and seasonal patterns are different between GSA 01 and GSA 03, what could indicate certain geographical disconnection. This disconnection might be related to local environmental conditions that can be different between north and south (Muñoz et al. 2015), but also likely to independent local dynamics of different population sub-units of a complex population of European hake in the Alboran Sea, as it has been already demonstrated in other Mediterranean Sea areas (Hidalgo et al., 2019). This general north-south segregating pattern is also suggested by genetic analyses of hake parasites collected all over the Alboran Sea. That is parasites markers (*Anisakis spp.*) hosted by Spanish European hake population seems to be different from those present in Moroccan hake (S. Mattiucci, TRANSBORAN project; Pers. Comm.) suggesting that Moroccan and Spanish hake are not sharing the same feeding ground as recruits and juveniles. The Atlantic Jet can be also amongst other factors behind this pattern acting like a barrier between north and south shores of Alboran Sea (Garcia-Lafuente et al., in press) that contribute to different regional environmental scenarios in the north and south (Muñoz et al 2015).

DFA also differentiates the ports of west and east suggesting thus secondary but relevant connection between GSA 01 and GSA 03 ports, which results more relevant in the ports of central part of the Alboran Sea. Thus, this result lets to argue that potential connectivity of early life stages (or lack of connectivity, attending to the hydrographic scenario each year; see discussion below) between GSA 01 and GSA 03 in the western part of Alboran is associated to the larger and more stable gyre (WAG). These results are consistent with the pattern observed in the nursery areas in the eastern Mediterranean (Reúl et al., 2005).In fact, it is more plausible that western gyre is the feature that is favoring connection of recruitment process at the west while the eastern half of the basin is dominated by the EAG which is usually smaller and more intermittent (Renault et al., 2012). *M.merluccius's* LPUEs in the Alboran Sea are likely conditioned, then, by local environmental factors, general oceanographic patterns over the whole Alboran Sea and biological and ecological processes of the species including a likely complex population's structure with population subunits in the north and south of the Alboran Sea.

The analysis of length distributions of hake in GSA 01 demonstrates that recruitment occurs in autumn-winter. This result is in line with Rey et al. (2004) about European hake recruitment in the Alboran Sea. This contrasts with higher abundances of hake reported in spring-early summer in other Western Mediterranean areas: Balearic island (Hidalgo et al., 2008), or Catalan sea, Gulf of Valencia (Castellón) and Bay of Alicante (Goñi et al., 2004). Geographically, this dynamics starts to change around the Gulf of Lions with maximum values in summer and autumn in the eastern Gulf of Lions, the northern Aegean Sea and specific areas of the eastern Ligurian and northern Tyrrhenian Seas (Belcari et al., 2001, Druon et al., 2015). It is believed that European hake recruitment is prolonged year-round with the presence of one or sometimes two seasonal peaks whose timing varies geographically, due to the existence of the “recruitment windows” driven by local environmental factors (Oliver, 1993). This might be the case of Alboran Sea especially since it is a transition zone for the Atlantic Ocean and the Mediterranean Sea.

Seasonal variability in life history traits and local population dynamics of the European hake has been reported by many studies (Oliver and Massutí, 1995, Maynou et al., 2003, Hidalgo et al., 2008, 2009). Actually, despite being a species with a protracted cycle along the year, European hake reproduction, spawning and recruitment have seasonal peaks that differ in different regions. Highest LPUEs in the first trend and second trend ,revealed by DFA ,matched recruitment peaks in spring and winter respectively as pointed by Rey et al (2003), while these two peaks are never observed in the whole Alboran being the recruitment process and thus the reproduction spatially structured. However, recruitment itself undergoes seasonal variability even being almost continuous throughout the year. This evidences that the two intra-annual reproduction peaks are not equally strong (Belacari et al.,2006, Recasents et al.,2008 , Ferrer-Maza et al.,2014) as spawning processes are generally evolutionary adapted to the most favorable environmental period that maximize the offspring survival and thus enhances recruitment process. From time series analysis of LPUE and length distribution, it can be deduced that, contrary to the other areas of western Mediterranean where recruitment pattern is quite homogeneous, recruitment pattern of European hake at Alboran Sea is quite heterogeneous. This suggests that the reproduction pattern, and by extension the population structure and its dynamics is more complex throughout the Alboran Sea.

Length distribution shows also inter-annual variation in GSA 01 as well as GSA 03 with considerable stability of distribution for GSA 01 since 2010 contrasted by a continuous shift toward smaller sizes at GSA 03.Despite of this trend, mean length is in general lower in Spain than Morocco where highest lengths are observed. This difference might be due to the Alboran southern shore geomorphology in the Moroccan continental shelf that is comparatively narrower facilitating the fleet access to deeper areas with larger specimens. The observed decrease of mean length of captured hake in Morocco can be caused by fishing pressure that is known to impact on size composition of demersal fish communities (Bianchi et al., 2000, Shin et al., 2005, Hsieh et al., 2010, Hidalgo et al., 2011, 2012). The year 2006 presents an abnormal distribution with exclusively smaller recruits; this most likely due to a misreported data since there is not a clear event reported in this year in the bibliography that could be behind this length distribution.

Spatial descriptors metrics were related suggesting that spatiotemporal changes in the nurseries of European hake in the north and south of Alboran Sea are most likely connected through the dispersal pattern in the western gyre during the early life stages. Those changes are clearer and significant for GSA 01 probably because of the higher number of sampled years contrary to GSA 03. Both density-dependent and independent movements are identified in the spatial metrics. Density is driving the population distribution in both GSAs with an increase in density triggering a northeast shift of center of gravity, and vice versa in years of low density in GSA 01. This displacements are due most likely to avoid intraspecific population competition and often conform to the widely predicted relationship between stock occupation area and abundance which has already been observed in other demersal and benthic species. For instance, Atlantic cod in the southern Gulf of St. Lawrence (Swain ,1990 , Swain & Wade 1993), juvenile haddock (*Melannogram musaeglefinus*) on the southwestern Scotian shelf (Marshall & Frank 1995), squid in the gulf of Cadiz (Delgado et al., 2018) and octopus in Northern Alboran (Puerta et al.,2014) displayed the same pattern.

Furthermore, spatial descriptors demonstrate that there is a north-south connection in hake distribution at Alboran Sea. First, the opposite longitudinal movement between the two GSAs, but also the bathymetric distribution of hake in GSA 03 that appears to be related to geographical location of centers of gravity of GSA 01. This result is consistent with the second trend of DFA analysis confirming the dependency of recruitment process between the two GSAs. This displacement in depths in GSA 03, instead of moving in longitude, undergoes a bathymetric displacement because of the small width of the Moroccan platform and the lack of horizonal space to change distribution. This bathymetric displacement in GSA3 occurs in years with weak density-dependent north east displacements in GSA 1 (i.e. competition reduced), which might occur in scenarios (i.e. year) where connectivity between north and south is high and very effective, increasing larval transport and relative in increase in the larval concentration in the south. By contrast, in years with stronger north south connectivity is lacking and/or not effective, competition may increase in the north (GSA1) with density-dependent changes in distribution, while bathymetric displacement in the south (GSA3) are not observed due to the likely lower larval abundance.

The obtained results of this study are timely especially giving that few studies have addressed populations structure in the Alboran Sea, particularly in important species for fisheries in the Morocco and Spain such as hake. A global scale, it is expected that the number of transboundary stocks will increase in the future (Pinsky et al .,2018), which makes highly important to understand how stable is the population structure of transboundary stocks. However, some limitations of the study may be cautiously considered in the conclusions. For instance, the shortness of time series could hide some information and limit the statistical significance. Also, national structural sampling of European hake that does not cover the whole Alboran and did not allow exploring length frequencies in some areas.

5. Conclusions

The main objective of the study was to analyze and to compare the spatiotemporal variation of fishery patterns, demographic indices and length distribution of European hake, *Merluccius merluccius*, in GSA 01 and GSA 03 in order to contribute in ameliorating knowledge about the delineation of European hake stock units, their population dynamics and spatial structure. The main findings of this study revealed:

1. General differentiation associated most likely to complex population substructure and thus contrasting local dynamics at the north and south Alboran as revealed by different seasonal and inter-annual variability with more spatial homogeneity within north Alboran ports.
2. A secondary segregation between eastern and western ports over the Alboran Sea with western ports associated to the same seasonal trend that describes LPUE time series variability.
3. Certain asynchronic, but connected, behavior in the spatial distribution of juvenile hakes at nursery areas between north and south Alboran Sea, most likely related to the inter-annual intermittence of the efficiency of connectivity process of early life stages between north and south.
4. Different size distributions between the two GSAs, with more temporal stability in Spain and smaller individuals in Spain consistent with the suggested differences attributed to the importance of local dynamics.

Furthermore, this study revealed that recruitment and the related ecological processes (i.e. spawning) is spatially structured in the Alboran Sea quite heterogeneous compared to other areas of Western Mediterranean and considering the size of the Alboran Sea.

6. References

Begg, G.A., Waldman, J.R. (1999) .An holistic approach to fish stock identification. Journal of Fisheries Research 43: 35-44.

Belcari, P., Ligas A,. Viva, C. (2006) .Age determination of the European hake , *Merlucciusmerluccius* (L.,1758) , in the north Tyrrhenian Sea (NW Meditirreanean). Journal of Fish Researchn,78: 211-217.

Belcari, P., Viva, C., Reale, B., Sartor, P., Sanchez, P., Demestre, M., Recasens, L., Lleonart, J., and Maynou, F. (2001). Factors affecting catch rates of NW Mediterranean trawl fleets and derivation of standardized abundance indices. Final Report, EU DGXIV, contract 98/053. 102 pp.

Bianchi, G., Gislason, H., Graham, K., Hill, L., Jin, X., Koranteng, K., Manickchand-Heileman, S., Paya´, I., Sainsbury, K., Sanchez, F., and Zwanenburg, K. (2000). Impact of fishing on size composition and diversity of demersal fish communities. ICES Journal of Marine Science, 57: 558-571.

Cadrin, S.X., Goethelb, D.R., Morsea, M.R., Faya, G., Kerr, L.A. (2019). "So, where do you come from?" The impact of assumed spatial population structure on estimates of recruitment. Journal of Fisheries Research., 219:156-168.

Cadrin, S.X., Kerr, L.A., Stefano, M. (eds) (2014). Stock identification methods: applications in fishery science. Academic Press.

Ciannelli, L., Fisher, J.A.D., Skern-Mauritzen, M., Hunsicker, M.E, Hidalgo, M., Frank, K.T., Bailey, K.M. (2013). Theory, consequences and evidence of eroding population spatial structure in harvested marine fishes: a review. Journal of Marine Ecology Progress Series, 480:227-243

Cohen, D.M., Inada, T., Iwamoto, T., Scialabba, N. (1990). FAO Species catalogue. Gadiform Fishes of the World (Order Gadiformes). An Annotated and illustrated Catalogue of Cods, Hakes, Grenadiers and other Gadiform Fishes known to Date. FAO Fish. Synopsis, 125(10) ,442 pp.

Colloca, F., Cardinale, M., Maynou, F., Giannoulaki, M., Scarcella, G., Jenko, K., Bellido, J. M., Fiorentino, F. (2013) .Rebuilding Mediterranean fisheries: a new paradigm for ecological sustainability. Journal of Fish and Fisheries, 14: 89–109

Coombs, S.H., and Mitchell C.E. (1982) .The development rate of eggs and larvae of the hake, *Merluccius merluccius* (L.) and their distribution to the west of the British Isles, *ICES* Journal of Marine Science, 40(2): 119-126.

CopeMed II (2017). Current knowledge on sardine and hake exploitation and status in the Alboran Sea, and the question of stock units identification. Occasional Paper OP 23, Alicante .29 pp

CopeMed II (2017). Report of the CopeMed II workshop on methodologies for the identification of stock units in the Alboran Sea. Technical Document 46,60pp

CopeMed II (2017). Current knowledge on Sardine and Hake exploitation and status in the Alboran Sea, and the question of stock unit's identification. Occasional Paper 23. Algiers, Algeria, 29pp

CopeMed II (2018). Report of the eleventh meeting of the CopeMed II coordination committee. Technical Document 49.Malaga, Spain, 36pp

De Mol, B,. Amblas; D., Calafat, A., Canals, M., Duran, R., Lavoie, C., Muñoz, A., Rivera; J., HERMESIONE. DARWINCD178. COBAS and Shipboard Parties. (2012). Cold-water coral colonization of Alboran Sea Knolls ,western Mediterranean Sea .In : Seafloor Geomorphology as Benthic Habitat: Geo HAB Atlas of Seafloor Geomorphic Features and Benthic Habitats . Harris, P.T., Baker, E.K., (eds) .Elsevier, 819–829.

De Pontual, H., Bertignac, M., Battaglia, A., Bavouzet, G., Moguedet, P., and Groison, A. L. (2003). A pilot tagging experiment on European hake (*Merluccius merluccius*): methodology and preliminary results. ICES Journal of Marine Science, 60: 1318-1327.

Delgado, M., Hidalgo, M., Puerta, P., Sanchez, R., Rueda , L., Sobrino ,I.(2018). Concurrent changes in spatial distribution of the demersal community in response to climate variations in the southern Iberian coastal Large Marine Ecosystem. Journal of Marine Ecology Progress Series, 607:19-36.

Domínguez-Petit, R. (2007). Study of reproductive potential of *Merluccius merluccius* in the Galician Shelf. PhD thesis, University of Vigo, Spain.

FAO (2003). Fish Stock Assessment Manual. FAO fisheries Technical Paper 393, Rome, Italy, 161pp.

FAO (2004). The conservation and management of shared fish stocks: legal and economic aspects. Technical Paper 465, Rome, Italy,79 pp.

FAO (2018). The State of World Fisheries and Aquaculture, 227pp.

FerrerMaza, D., Lloret, J., Muñoz, M., Faliex, E., Vila, S.,Sasal, P. (2014).Parasitm , condition and reproduction of the European hake (*Merluccius merluccius*) in the north-western Mediterranean Sea. ICES Journal of Marine Science ,71:1088–1099

Froese, R., and Kesner-Reyes, K. (2002). Impact of Fishing on the Abundance of Marine Species, ICES CM 2002/: 12, ICES Conference and Meeting (CM) documents, Copenhagen.

García-Gorriz, E., and Carr, M.E. (2001). Physical control of phytoplankton distributions in the Alborán Sea: A numerical and satellite approach. Journal of Geophysical Research , 106(C8):16795–16805.

García-Lafuente, J., Sanchez-Garrido, J.C., Garcia, A., Hidalgo, M., Sammartino, S, Laiz- Carrión. (in press) . Biophysical processes determining the connectivity of fish populations in the Alboran Sea. In: Ecology, Oceanography and Fisheries of the Alboran Sea. Springer.

Garcia-Rodriquez, M., and Esteban, A. (2002). How fast does hake grow? A study on the Mediterranean hake (*Merluccius merluccius* L.) comparing whole otoliths readings and length frequency distributions data. Journal of Scientia Marina, 66 :145–156.

GFCM. (2018). Report of the Working Group on Stock Assessment of Demersal Species (WGSAD), Rome

Goikoetxea, N., & Irigoien, X. (2013). Links between the recruitment success of northern European hake (*Merluccius merluccius* L.) and a regime shift on the NE Atlantic continental shelf. Journal of Fisheries Oceanography, 22 :459–476

Goñi, R., Adlerstein, S., Alvarez, F., Garcia, M., Sanchez, P., Sbrana, M., Maynou, F., and Viva, C. (2004). Recruitment indices of European hake, *Merluccius merluccius* (Linnaeus 1758), in the Northwest Mediterranean based on landings from bottom-trawl multispecies fisheries. ICES Journal of Marine Science, 61: 760-773.

Hastie, T., and Tibshirani, R. (1990). Generalized Additive Models. Chapman and Hall , London

Hidalgo, M. (2008). Recruitment process and population dynamics of the European hake (*Merluccius merluccius* L.) off the Baleric Islands:seasonal and inter-annual approach. PhD thesis, University of Baleres , Palma de Mallorca, Spain.

Hidalgo, M., Massutı´, E., Moranta, J., Cartes, J., Lloret, J., Oliver, P., Morales-Nin, B. (2008). Seasonal and short spatial patterns in European hake (*Merluccius merluccius* L.) recruitment process at the Balearic Islands (western Mediterranean): the role of environment on distribution and condition. Journal of Marine Systems, 71: 367–384

Hidalgo, M., Tomas, J., Moranta, J., Morales-Nin, B. (2009). Intra-annual recruitment events of a shelf species around an island system in the NW Mediterranean. Journal of Estuarine, Coastal and Shelf Science, 83: 227–238.

Hidalgo, M., Rouyer, T., Molinero, JC., Massutí, M., Moranta, J., Guijarro, B., Stenseth, NC. (2011). Synergistic effects of fishing-induced demographic changes and climate variation on fish population dynamics. Journal of Marine Ecology ProgressSeries,426:1−12

Hidalgo, M., Rouyer, T., Bartolino, V., Cerviño, S. (2012).Context-dependent interplays between truncated demographies and climate variation shape the population growth rate of a harvested species. Journal of Ecography, 35: 637−649

Hidalgo, M., Rossi , V., Monroy, P., Ser-Giacomi E., Hern_andez-Garc, E., Guijarro B., Massuti E., Alemany, F., Jadaud A., Perez J. L., Reglero, P. (2019.). Accounting for ocean connectivity and hydroclimate in fish recruitment fluctuations within transboundary metapopulations. Journal of Ecological Applications, 29(5):e01913

Holmes, E.E., Ward, E.J., Wills, K.(2012). MARSS , multivariate autoregressive state-space models for analyzing time series data. The R journal, 4:11-19.

Hsieh, C.H., Reiss, C.S., Hewitt, R.P., Sugihara, G. (2008). Spatial analysis shows that fishing enhances the climatic sensitivity of marine fishes. Canadian Journal of Fisheries and Aquatic Sciences, 65:947−961

Ifremer. (2016). Biologie du merlu.

Ihssen, P. E., Bodre, H. F., Casselman, J. M., McGlade, J. M., Payne, N. R., Utter, F. (1981). Stock identification: materials and methods. Canadian Journal of Fisheries and Aquatic Sciences, 38: 1838–1855.

Inada, T. (1981). Studies on the Merlucciid Fishes. Bulletin Far Seas Fisheries Research Laboratory, 18: 1–172.

INRH(2018) . Etat des Stocks et des Pêcheries au Maroc 2016 ; Institut National de Recherche Halieutique , 296 pp

Kerr L, Hintzen, N.T., Cadrin, S.X., Clausen L.W, Dickey-Collas M., Goethel, D.R., Hatfield E.M.C., Kritzer, J.P., Nash, R.D.M. (2017) . Lessons learned from practical approaches to reconcile mismatches between biological population structure and stock units of marine fish. ICES Journal of Marine Science, 74(6) : 1708–1722

Kumpf, H.E., Vaught, R.N., Grimes, C.B., Johnston A.G., Nakamura, E.L., (eds) (1987). Proceedings of the Stock Identification Workshop. NOAA Technical Memorandum NMFS-SEFC-199. Washington.

Lleonart , J. (2015). Mediterranean Fisheries. Stocks, Assessments and Exploitation Status. IEMed Mediterranean Yearbook ,Barcelona, 276-281.

Lleonart, J. (2015). Mediterranean Fisheries. Stocks, Assessments and Exploitation Status. Journal of Strategics Sectors | Economy & Territory: 276-281

Lloris, D., Matallanas,J., Oliver, P. (2003). Merluzas del mundo (Familia Merlucciidae). Catálogo comentado e ilustrado de las merluzas conocidas. FAO Catálogo de especies para los fines de la pesca, 69 pp.

Macias, D. Garcia –Gorriz E., and Stips A. (2016). The seasonal cycle of the Atlantic Jet dynamics in the Alboran Sea: Direct Atmospheric Forcing versus Mediterranean Thermohaline circulation. Journal of Ocean Dynamics , 66:137–151.

Marshall, C.T, Frank, K.T. (1995). Density-dependent habitat selection by juvenile haddock (*Melanogrammus aeglefinus*) on the south-western Scotian Shelf. Canadian Journal of Fisheries and Aquatculture Science, 52:1007–1017

Mattiucci, S. (July, 2019). Analysis of Anisakis spp. in European hake. CopeMed II Interim Mid-term workshop, Malaga ,Spain

Maynou, F., Lleonart; J., Cartes, J.E. (2003). Seasonal and spatial variability of hake , *Merluccius merluccius*, recruitment in the NW Mediterranean. Journal of Fisheries Research, 60: 65–78.

Muñoz, M., Reul, A., Plaza, F., Gomez-Moreno, M.-L., Vargas-Yañez, M., Rodriguez, V., Rodriguez, J. (2015). Implication of regionalization and connectivity analysis for marine spatial planning and coastal management in the Gulf of Cadiz and Alboran Sea. Journal of Ocean & Coastal Management, 118 : 60–74.

Muñoz , M., Reul, A., Gil de Sola, L., Lauerburg, R.A.M., Tello, O., Gimpel, A.(2018). A spatial risk approach towards integrated marine spatial planning: A case study on European hake nursery areas in the North Alboran Sea. Journal of Marine Environmental Research, 142:190-207.

Oliver, P. (1993). Analysis of fluctuations observed in the trawl fleet landings in the Balearic Islands. Journal of Scientia Marina, 57: 219-227

Oliver, P., and Massutí, E. (1995). Biology and fisheries of western Mediterranean hake (M. *merluccius*). In : Alheit J. & Pitcher T.J. (eds) : Hake: Fisheries, Ecology and Markets. Fish and Fisheries Series.15. Chapman and Hall, London, pp. 181-202.

Papaconstantinou C. (2000) The biology and the management of Hake (*Merluccius merluccius*) in the Greek Seas. Working paper presented at WG on Demersales., 17 pp.

Parrilla, G., Kinder, T.H.(1987). The Physical Oceanography of the Alboran Sea. NORDA Report, 184pp.

Perkins, H., T. Kinder, La Violette, P.E.(1990). The Atlantic Inflow in the Western Alboran Sea. Journal of Physical Oceanography,20:242–263.

Philips, A.E.(2012). Feeding Behaviour of the European hake *Merluccius merluccius* Linnaeus, 1758 (Family: Gadidae) from Egyptian Mediterranean waters off Alexandria. Egyptian Journal of Aquatic Research ,38: 39–44.

Pillar, S. C., and Barange, M. (1995) .Diel feeding periodicity, daily ration and vertical migration of juvenile Cape hake off the west coast of South Africa. Journal of Fish Biology , 47(5): 753–768.

Piñeiro C. Rey J. de Pontual H. , García A. (2008). Growth of Northwest Iberian juvenile hake estimated by combining sagittal and transversal otolith microstructure analyses. Journal of Fisheries Research, 93: 173–178

Puerta, P., Hidalgo, M., González, M., Esteban, A., Quetglas, A.(2014). Role of hydro-climatic and demographic processes on the spatio-temporal distribution of cephalopods in the western Mediterranean. Journal of Marine Ecology Progress Series, 514: 105–118

Quetglas, A., Guijarro, B., Ordines, F., Massuti, E. (2012). Stock boundaries for fisheries assessment and management in the Mediterranean: the Balearic Islands as a case study. Journal of Scientia Marina, 76: 17–28.

Quinteiro, J., Vidal, R., Izquierdo, M., Sotelo, C.G., Chapela, M.J., Pérez-Martín, R.I., Rehbein, H., Hold, G.L., Russel, V.J., Pryde, S.E., Rosa, C., Santos, A.T., Rey-Méndez, M.(2001). Identification of hake species (*Merluccius* genus) using sequencing and PCR-RFLP analysis of mitochondrial DNA control region sequences. Journal of Agriculture and Food Chemistry , 4:5108–5114.

Recasens, L., Chiericoni, V., and Belcari, P. (2008). Spawning pattern and batch fecundity of the European hake (*Merluccius merluccius* (Linnaeus, 1758)) in the western Mediterranean. Journal of Scientia Marina, 72: 721–732

Renault, L., Oguz, T., Pascual, A., Vizoso, G., Tintore, J. (2012) .Surface circulation in the Alboran Sea (western Mediterranean) inferred from remotely sensed data. Journal of Geophysical Resarch:Oceans, 117(C8).

Rey, J., and Gil de Sola, L. (2004). Seasonal recruitment of hake in the Alboran Sea (SW Mediterranean). Rapp. Comm. Int. Mer Medit. 37: 427.

Shin, Y-J., Rochet, M-J., Jennings, S., Field, J.G., Gislason, H. (2005). Using size-based indicators to evaluate the ecosystem effects of fishing. ICES Journal of Marine Science, 62(3): 384–396.

Stagioni, M., Montanini, S., Vallisneri, M. (2011). Feeding habits of European hake, *Merluccius merluccius* (Actinopterygii: Gadiformes: Merlucciidae), from the north eastern Mediterranean Sea. Journal of Acta Ichthyologica et Piscatoria , 41 (4): 277–284.

Swain, D.P., Wade, E.J.(1993) Density-dependent geographic distribution of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence. Canadian Journal of Fisheries and Aquaculture Science .,50 (4): 725–733.

Swain, D.P. (1999) .Changes in the distribution of Atlantic cod (*Gadus morhua*) in the southern Gulf of St. Lawrence — effects of environmental change or change in environmental preferences. Journal of Fisheries Oceanography, 8:1–17.

Tanner, S. E., Reis-Santos, P., Cabral, H. N. (2016) Otolith chemistry in stock delineation: A brief overview, current challenges and future prospects. Journal of Fisheries Research, 173: 206–213.

UNEP/MAP/PAP (2014). Status of the Open Sea Fisheries in the Alboran Sea.

UNEP/MAP/PAP (2015). Status of the Open Sea Fisheries in the Alboran Sea.

Vargas-Yáñez; M., Plaza, F., García-Lafuente, J., Sarhan, T., Vargas, J.M., Vélez-Belchi, P. (2002).About the seasonal variability of the Alboran Sea circulation. Journal of Marine Systems ,35: 229-248.

Vitale S., Andrews A.H., Rizzo P., Gancitano, S., Fiorentino, F. (2016). Twenty-five-year longevity of European hake (*Merluccius merluccius*) from novel use of bomb radiocarbon dating in the Mediterranean Sea. Journal of Marine and Freshwater Research .,67: 1077-1080.

Zuur, A.F., Fryer, R.J, . Jollife, I.T., Dekker, R., Beukema, J.J. (2003). Estimating common trends in multivariate time series using dynamic factor analysis. Journal of Environmetrics, 14: 665-685.

7. Webography

http://www.faocopemed.org/ (Consulted03/04/2019)

http://www.fishbase.org/summary/Merluccius-merluccius.html(Consulted07./04/2019)

https://www.fisheries.noaa.gov/feature-story/fish-stock-assessment-101-series-part-1 data-required-assessing-us-fish-stocks(Consulted Consulted 03/04/2019)

http://www.europarl.europa.eu/legislative-train/theme-fisheries/file-multiannual-plan-for demersal-fisheries-in-the-western-mediterranean(Consulted 15/05/2019)

Universitat d'Alacant
Universidad de Alicante

GOBIERNO DE ESPAÑA

MINISTERIO DE AGRICULTURA, PESCA Y ALIMENTACIÓN

CIHEAM

El Máster Internacional en GESTIÓN PESQUERA SOSTENIBLE está organizado conjuntamente por la Universidad de Alicante (UA), el Centro Internacional de Altos Estudios Agronómicos Mediterráneos (CIHEAM) a través del Instituto Agronómico Mediterráneo de Zaragoza (IAMZ), el Ministerio de Agricultura, Pesca y Alimentación (MAPA) a través de la Secretaría General de Pesca (SGP).

El Máster se desarrolla a tiempo completo en dos años académicos. Tras completar el primer año (programa basado en clases lectivas, prácticas, trabajos tutorados, seminarios abiertos y visitas técnicas), durante la segunda parte los participantes dedican 10 meses a la iniciación a la investigación o a la actividad profesional realizando un trabajo de investigación original a través de la elaboración de la Tesis Master of Science. El presente manuscrito es el resultado de uno de estos trabajos y ha sido aprobado en lectura pública ante un jurado de calificación.

The International Master in SUSTAINABLE FISHERIES MANAGEMENT is jointly organized by the University of Alicante (UA), the International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) through the Mediterranean Agronomic Institute of Zaragoza (IAMZ), and by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA) through the General Secretariat of Fisheries (SGP).

The Master is developed over two academic years. Upon completion of the first year (a programme based on lectures, practicals, supervised work, seminars and technical visits), during the second part the participants devote a period of 10 months to initiation to research or to professional activities conducting an original research work through the elaboration of the Master Thesis. The present manuscript is the result of one of these works and has been defended before an examination board.